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THE STORY OF THE ENGINE

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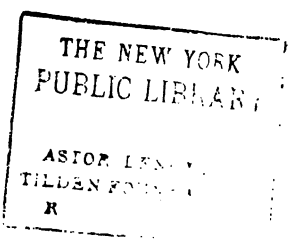
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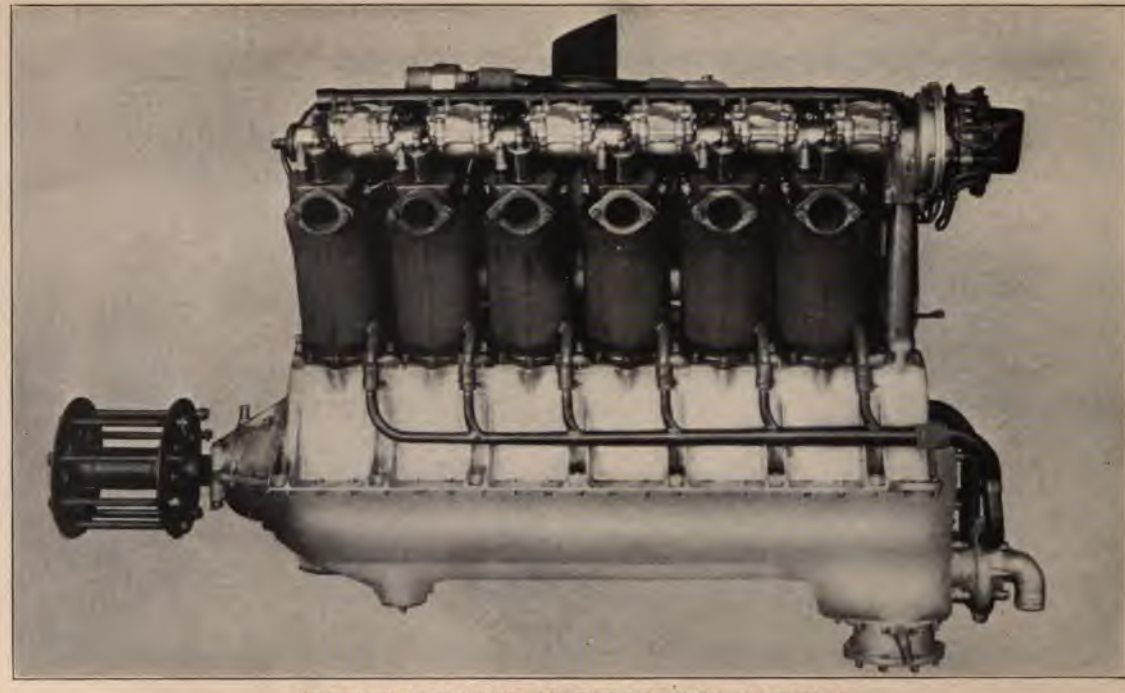

TWELVE CYLINDER LIBERTY MOTOR—MODEL A

From a photograph furnished by the United States War Department Air Service

THE STORY OF THE ENGINE

FROM LEVER TO LIBERTY MOTOR

BY

WILBUR F. DECKER, M. E.

ILLUSTRATED

NEW YORK
CHARLES SCRIBNER'S SONS
1920

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PREFACE

THE wide-awake young man who is looking forward to a successful career as an engineer or inventor will find it necessary to consult many sources of information other than advanced scientific text-books. Indeed, the authors of all advanced works on mechanical subjects assume that their readers have already acquired a general knowledge of machinery and engines.

The most useful information, in any line, is usually that which is dug up in the field of practical experience; but circumstances do not often favor young men with this kind of schooling in mechanics—excepting occasionally in restricted fields. Fortunately, the HOW and WHY of mechanism and power generators can be almost as easily explained by means of cuts, diagrams, and the printed page, as by the examination of actual machines.

It is the aim of this book to show how man first learned to apply mechanical principles; to trace the gradual development of heat-engines; to furnish accurate and reliable information regarding present-day types, and to prepare the way for possible later scientific studies.

Chapter I deals with the so-called "mechanical powers," some of which have been known and applied for thousands of years; some recent applications of old principles are also pointed out.

OCT 1937

The chapters which follow are devoted to a rather full discussion of steam and other heat engines—so far as this can be done without employing the higher mathematics. The Liberty Motor is fully discussed as a crowning example of mechanical achievement. The final chapter is devoted to oil-engines and an explanation of the principle of the Diesel engine.

Of the one hundred and sixty-four illustrations, all but five have been drawn by the author especially for this book. The frontispiece is reproduced, by permission of the United States War Department Air Service, from a photograph of a Model A Liberty Motor.

Figures 109, 110, 111, and 112 are reproductions of drawings kindly furnished by the Westinghouse Electric and Manufacturing Company, of Pittsburgh.

Figures 102, 103, 104, and 113 are from line-drawings made by the author from other photographs furnished by the Westinghouse Company. Grateful acknowledgment is also made to the American Locomotive Company, of New York, the Baldwin Locomotive Company, of Philadelphia, and the Packard Motor Car Company, of Detroit, for courtesies rendered.

W. F. D.

MINNEAPOLIS, March, 1920.

CONTENTS

CHAPTER I

PAGE

INTRODUCTORY—ELEMENTARY MACHINES 1

Discovery of the use of the lever—How the knowledge was passed on—One discovery led to another—Principles of action, finally established—Applications to new uses—Examples of the various kinds of levers—Carpenter's hammer—Metal shears—System of levers—Cog-wheels—Wheel and axle—The crank—Locomotive driving-wheels, short stroke and high wheels for speed; long stroke and low wheels for freight service—The inclined plane—Inclined roadways—The wedge—The screw, a useful application of the inclined plane—The movable pulley—Applications of the movable pulley—Chain-blocks—Cylinders and pistons—Single-acting cylinder—Double-acting cylinder—Valves—Common check-valve.

CHAPTER II

EARLY STEAM-ENGINES 21

Newcomen's pumping-engine—Humphrey Potter, a bright boy, improves the Newcomen engine—The atmosphere—How Newcomen took advantage of atmospheric pressure—The vacuum and partial vacuum—James Watt—His discovery of the weak points of the Newcomen engine—Watt invents the separate condenser and air-pump—Direct steam pressure employed—Watt uses steam expansively—The sun-and-planet motion—Crank motion—Watt invents the double-acting cylinder—Watt's parallel motion—Watt's business success and great contribution toward modern progress.

CHAPTER III

STEAM-BOILERS, FURNACES, AND CONNECTIONS . . . 36

Generating steam—Newcomen and Watt employed low-pressure steam—Modern steam-boilers must be very strong—The cylindrical boiler—How additional heating surface is gained—Heat the result of chemical action and real source of the energy of the steam-engine—

Open, semi-open and closed fires—Importance of the chimney—The grate—Forced drafts—Waste of heat up the chimney—The vertical boiler—Boiler accessories, safety-valve, steam-gauge, water-gauge, etc.—The horizontal tubular boiler—Bridge wall—Combustion-chamber—Smoke-box—Smoke-stack—Batteries of boilers—The locomotive boiler—Many tubes of small diameter—Exhaust nozzle—Fire-box surrounded by water—The Scotch marine boiler—Independent furnaces, combustion-chambers, and sets of tubes—Stay-rods — Stay-bolts — Gusset-stays — Girder-stays — Single-enders — Double-enders—Boilers of the Cunard liner *Aquitania*—Fifty-four miles of tubes in her twenty-one boilers—Various kinds of boiler joints—Calking — Water-tube boilers — Superheaters — Travelling grates —Waste of fuel through bad firing—Steam-fittings—Strength of large and small cylinders and pipes—Balanced valves.

CHAPTER IV

RECIPROCATING ENGINES 61

The double-acting horizontal engine—The D-slide valve—Cross-head—Connecting-rod—Fly-wheel—Guides—Valve-gearing—Eccentric—Steam-ports—Lap—Effect of eccentric motion on movement of valve—Lead—Cut-off—Cushioning—Objections to the use of the slide-valve—The balanced slide-valve—Auxiliary valves—Various forms of cross-heads—Balanced cranks—Double cranks—Connecting-rod ends—Pillow-blocks—Thrust-bearings—The link motion—Hooking up—Pistons—Stuffing-boxes—Vertical engines—Marine engines—The governor—Corliss engines—Corliss valves—The Corliss valve-gear—The Corliss cut-off—Dash-pot—Tandem cylinders—Compound engines—Triple and quadruple expansion-engines—The condenser — Jet-condensers — Surface-condensers — Separators — Condensers impractical in locomotive practice.

CHAPTER V

THE LOCOMOTIVE 102

Inventions of Gugnot and Trevithick—Stephenson's "Rocket"—The Rocket compared with the modern locomotive—The development of the modern locomotive—Large fire-boxes necessary—Piston valves—Improved valve-gear—Limitations of the standard gauge—Grates and shaking devices—Artificial draft—The frame and springs —Driving-blocks—Equalizing bars and hangers—Three-point suspension—Driving-wheels and tires—Conical tread—Flanges—Cylinder castings complicated—Action of the cylindrical slide-valve, with inside admission—Dry steam from the steam-dome—The

throttle-valve—Objections to the use of the Stephenson valve-gear—The Walschaert valve-gear—The Kingan-Ripkin valve-gear—The return-crank—Lap and lead lever—Guides—Details of the steam-gauge—The injector—The pop safety-valve—The steam-whistle—Various types of the locomotive—Tractive force—Elimination of dead centres.

CHAPTER VI

THE STEAM-TURBINE 128

Hero's engine, a forerunner of the modern turbine-engine—Branca's engine—Reasons why these were not successful—Steam-jets and nozzles—The expanding nozzle—Velocity of steam-jets—Weight and momentum of steam—The steam-jet compared with the discharge of a machine-gun—Action of a steam-jet on curved vanes—High velocity of rotors—De Laval's impulse turbine—Small diameter of De Laval rotors—Perfect balance necessary—Flexible shafts—Critical speed—Methods of mounting rotors—Capacity of small shafts in rapid revolution—Pressure and velocity diagrams—Double impulse rotors—Reduction gears—Direct-acting turbo-generators—Reversing chambers—The turbine governor—Flexible bearings—Safety devices—Reaction turbines—Parsons's invention—Reaction of steam-jet like "kick" of gun—Reaction caused by increasing speed—Fixed and movable blades—Increase of volume as exhaust is approached—Parsons's rotors and casings—Single-flow reaction turbines—Dummies and equilibrium pipes—Great advantage of the use of the condenser—Combination impulse and reaction single-flow turbine—The double-flow turbine—Semi-double-flow turbine—Necessity for wide and roomy exhaust—Method of attaching reaction blading—Necessity for perfect workmanship—Multiple-stage turbines—Reaction turbines used in connection with exhaust of reciprocating engines—Small size of steam-turbines as compared with reciprocating engines of like power—Marine turbines—Turbines non-reversible—Astern turbines—Actual weight of steam used in large turbines—Steam-turbine a true heat-engine—Thermodynamics—Improvements often made by untechnical men.

CHAPTER VII

MEASUREMENTS OF POWER 164

Improper use of terms—Force defined—Gravity—Draw bar pull—Pressure—Work—The foot-pound—Energy—Potential energy—Active energy—Power—Efficiency—Horse-power—Kilowatts—Indicated horse-power—Brake horse-power—Methods of ascertaining

horse-power of an engine—An easy formula—Unequal pressure—The indicator—Method of using the indicator—What the indicator reveals—Indicator diagrams—Analysis of diagrams—Corliss-engine diagrams—High-speed diagrams—Importance of knowing the actual working-power of an engine—The friction-brake—Method of calculating brake horse-power—Measuring the power of electric-light engines.

CHAPTER VIII

GAS-ENGINES 178

Internal-combustion engines compared with steam-engines—The four-cycle gas-engine—Heavy fly-wheel necessary—The hot-tube method of ignition—Importance of close-fitting piston and valves—Advantage of conical valves—High-pressure of expanding charge—Strong parts necessary—Water-jackets—Circulating-pump and radiator—Special lubricating-oil necessary—Power employed to compress charge not wasted—The gas-producer—Producer gas——Suction producers—Gas-producer details—The mixing of producer gas and water-gas—Soft-coal producers—By-products—The gas-engine governor—Hit-or-miss system—Difficulties of starting gas-engines—Starting devices—Two-cycle gas-engines.

CHAPTER IX

GASOLINE-ENGINES 197

The gasoline-engine has supplied a great need—Wide-spread use, on land, on water, and in the air—Comparison with the gas-engine—The four-cycle gasoline-engine—The "T," "L," and "valve in head" types—Timing-gears—The carburetor—Difficulty of starting a cold engine—Priming—Indications of too much gasoline—Lean mixture for fast running—Extra air-valve—Effect of atmospheric conditions—Manifolds must be gas-tight—The vacuum tank—Ignition—Pre-ignition—Diagrams show enormous pressure at beginning of stroke—Electric sparking devices—Positive and negative poles—The dry-cell—"In Series" arrangement of battery—"In Series Parallel" arrangement—Good and poor conductors—Necessity for insulation—The spark—Make-and-break system—The jump-spark system—The spark-plug—The induction coil—Primary and secondary windings—The vibrator—The timer—The complete sparking device—Timers for multiple-cylinder engines—The two-cycle engine—Its advantages and its disadvantages—Advantage in the use of multiple cylinders—Ninety degree and one-hundred-and-twenty degree cranks—Two cylinders operating a single crank—The "V" type of motor—The

forked connecting-rod and long bushing—Circulating pumps and radiators—Air cooling—Motors for airplanes—Great power and light weight needed—Great progress in Europe—Circumstances that led to design of Liberty Motor—Remarkable performance of the Liberty Motor—Dimensions of parts of Liberty Motor—Weight less than two pounds per horse-power—Cam-shafts at top of cylinders—Hollow parts—Electric welding employed—Extreme lightness of connecting-rods compared with the power they transmit—Comparison of Wright brothers' early engines with the Liberty Motor—Gradual increase of weight—Power increases at a much more rapid rate—Great reduction in fuel consumption per horse-power.

CHAPTER X

OIL-ENGINES 249

Demand for engines using low-priced fuel—Difficulty of vaporizing heavy oils—Advantages of high compression—Its disadvantages—The Diesel engine—Great stores of liquid fuel made available—Utilization of by-products—Dr. Diesel's claims—Utilization of heat of compression—Rapid combustion, but no explosions—Fuel oil introduced after compression occurs—Method of introducing the fuel—Cylinders and pistons unusually long—Many packing-rings necessary—Peculiar cylinder-head—Auxiliary air-compressor—The air-valve—Method of starting a Diesel engine—Method of operating valves—Necessity for high-grade workmanship—No danger of pre-ignition—The two-cycle Diesel engine—Scavenging devices—Multiple-cylinder Diesel engines—First cost high—Economy of operation—The semi-Diesel engine—The hot-pot—No heat from outside source needed after engine is once started.

INDEX 273

ILLUSTRATIONS

Liberty Motor, Model A . . . . . *Frontispiece*

FIG.		PAGE
1.	Discovery of the use of the lever	2
2.	Diagrams illustrating various kinds of levers	4
3.	The carpenter's hammer, used as a lever	6
4.	Metal shears, an illustration of the lever	6
5.	A combination of levers	7
6.	Cog-wheels, an illustration of lever action	8
7.	The wheel and axle, illustrating lever action	9
8.	Locomotive driving-wheels illustrating lever action	10
9.	The inclined plane	11
10.	Combination of inclined plane and rollers	11
11.	The wedge, an example of the inclined plane	12
12.	The common screw, jack-screw, machine-bolt—examples of the inclined plane	13
13.	The movable pulley	15
14.	"Tackle and fall," "chain-blocks"—examples of the movable pulley and the differential pulley	17
15.	Cylinders—single-acting and double-acting	18
16.	The common check-valve	19
17.	Newcomen's pumping-engine	22
18.	Watt's single-acting steam-cylinder	27

FIG.		PAGE
19.	Watt's improved steam-cylinder	29
20.	Watt's sun-and-planet motion	32
21.	Watt's parallel motion	34
22.	Examples of open, semi-open, and closed fires	38
23.	Section of an upright steam-boiler	40
24.	Section of a horizontal steam-boiler, furnace, and combustion-chamber	44
25.	Section of a locomotive boiler	46
26.	Sections and half elevation of a Scotch marine boiler	49
27.	Section of an agitator for a marine boiler	50
28.	Stay-rod for a marine boiler	51
29.	Gusset-stay for supporting a boiler-head	51
30.	Double-riveted joint	52
31.	Double-riveted butt-joint	52
32.	Calking a boiler joint	53
33.	Water-tube boiler	54
34.	Flanged joint for steam-pipes	57
35.	Pipe-fittings—elbow, short nipple, tee, long nipple, union-joint, coupling, 45°-elbow, and plug	58
36.	Diagrams illustrating pressure on large and small cylinders	58
37.	Balanced throttle-valve	59
37a.	Hand-lever for throttle-valve	59
38.	Horizontal slide-valve engine	62
39.	Horizontal engine with steam-chest on the side. (Top view)	63

FIG.		PAGE
40.	Eccentric, eccentric-strap, and eccentric-rod	64
41.	Slide-valve in middle position, showing lap	65
42.	Guide for valve connection	70
43.	Balanced slide-valve	70
44.	Meyer's cut-off valve	71
45.	Cross-head for non-reversible engine	72
46.	Cross-head for reversible engine	72
47.	Diagrams illustrating upward and downward pressure on guides	73
48.	Common crank	74
49.	Balanced disk-crank	74
50.	Double cranks and journals	75
51.	Connecting-rod end	76
52.	Various forms of connecting-rod ends	77
53.	Forked connecting-rod end	78
54.	Pillow-block	79
55.	Thrust-block for marine-shaft	80
56.	Stephenson link motion	80
57.	Link, in neutral position	81
58.	Reversing-lever for operating link	82
59.	Common piston	83
60.	Built-up piston—dome shaped	83
61.	Stuffing-box	84
62.	Reversible vertical engine	85
63.	Governor	86

FIG.		PAGE
64.	Corliss valves	87
65.	Corliss valve in housing	88
66.	Corliss valve-gearing	89
67.	Corliss valve cut-off device	91
68.	Corliss valve released	91
69.	Dash-pot—sectional view	94
70.	Diagram of a compound steam-engine	96
71.	Jet-condenser and air-pump	98
72.	Surface-condenser	100
73.	Stephenson's "Rocket," the first practical locomotive	103
74.	Modern passenger-locomotive	106
75.	Locomotive grate and ash-pan	107
76.	Locomotive exhaust-nozzle	108
77.	Locomotive frame	109
78.	Locomotive driving-block	109
79.	Locomotive springs and equalizing levers	110
80.	Section of a locomotive tire	111
81.	Section of locomotive cylinders, showing method of attaching them to the frame and to the smoke-box	113
82.	Cylindrical slide-valve for inside admission	114
83.	Locomotive steam-dome and throttle-valve	115
83a.	Throttle lever	115
84.	Kingan-Ripkin valve-gear	117
85.	Locomotive cross-head guides	120
86.	Steam-gauge	121

FIG.		PAGE
87.	Diagrams illustrating the principle of the injector	122
88.	Pop safety-valve	124
89.	Steam-whistle	125
90.	Hero's reaction engine	128
91.	Branca's impulse engine	128
92.	Steam escaping from orifice	130
93.	Steam escaping from an expanding-nozzle	130
94.	Action of steam-jet on a curved vane	133
95.	Diagram illustrating De Laval's steam-turbine	135
96.	De Laval's impulse-wheel, or rotor	137
97.	De Laval blading, showing method of attachment to rotor	137
98.	Section of De Laval rotor, showing one method of attaching flexible shaft	139
99.	Diagrams showing action of steam-jet on a single set of blading	140
100.	Diagram showing action of steam-jet on a double impulse wheel	140
101.	Spiral reduction pinions	142
102.	Westinghouse 10-kilowatt turbo-generator	143
103.	Section of 10-kilowatt turbine-motor	144
104.	Westinghouse impulse rotor, showing nozzle and reversing chamber	145
105.	Flexible bearing	147
106.	Safety device for rotor shaft	147
107.	Diagram of reaction blading	149

FIG.		PAGE
108.	Diagram illustrating action of fixed and moving blades	150
109.	Section of Parsons type single-flow turbine	152
110.	Section of a combination impulse and reaction single-flow turbine	154
111.	Section of a double-flow turbine	155
112.	Section of a semi-double-flow turbine	155
113.	Illustration of the method of securing reaction blading to rotors	156
114.	Sections of fastenings	157
115.	Section of multiple-stage impulse turbine	158
116.	Diagram of steam-engine indicator	169
117.	Steam-engine diagram	170
118.	Illustration of method of measuring diagrams	173
119.	Corliss-engine diagram	174
120.	Diagram of high-speed engine	175
121.	Apparatus for measuring brake horse-power	175
122.	Diagrams illustrating action of a four-cycle gas-engine	179
123.	Section of a gas-producer, vaporizer, and scrubber	188
124.	Gas-engine governor	191
125.	Section of a four-cycle gasoline-engine	201
126.	The L-type of cylinder-head	204
127.	Valve-in-head mechanism	204
128.	Cam and rocker-arm for operating push-rods	205
129.	Diagram of carburetor	206
130.	Gasoline-engine diagrams	213

FIG.		PAGE
131.	Section of common dry-battery cell	217
132.	Battery-cells connected in series	218
133.	Battery-cells connected in series-parallel	218
134.	Section of common spark-plug	220
135.	Diagram illustrating action of induction coil	222
136.	Induction-coil vibrator	224
137.	Diagram of battery, induction coil, vibrator, timer, and spark-plug	226
138.	Section of two-cycle engine	227
139.	Double cylinders and cranks	230
140.	Cranks for three and six cylinder engines	232
141.	Diagram showing positions of pistons and cranks in a six-cylinder engine	232
142.	Diagram of V-type motor	233
143.	Connecting-rods and bushings for V-type motor	234
144.	Centrifugal circulating pump	235
145.	Section of air-cooled cylinder	237
146.	Section of air-cooled cylinder, with detachable flanges.	237
147.	General view of a Liberty Motor	242
148.	Liberty Motor valve rocker-arms	243
149.	Liberty Motor hollow cam-shaft	243
150.	Liberty Motor cylinder and water-jacket	244
151.	Liberty Motor piston	245
152.	Liberty Motor connecting-rod	246
153.	Liberty Motor manifold	247

FIG.		PAGE
154.	Diesel-engine diagram	253
155.	Section of Diesel engine and air-compressor	255
156.	Section of Diesel-engine head, showing air-valve and connections	257
157.	Detachable lever-arm for operating air and exhaust valves	258
158.	Section of Diesel-engine head showing starting and fuel valves	259
159.	Section of fuel-valve	260
160.	Fuel-valve cam	264
161.	Starting-valve cam	264
162.	Section of two-cycle Diesel-engine cylinder, showing scavenging and exhaust passages	266
163.	Section of two-cycle semi-Diesel engine	269

THE
STORY OF THE ENGINE

THE STORY OF THE ENGINE

CHAPTER I

INTRODUCTORY. ELEMENTARY MACHINES

SURROUNDED as we are by modern conveniences, it is difficult for us to realize that there was once a time when man lived much like the animals, without any knowledge of the arts or of the simplest implements with which we are familiar.

THE LEVER. No one knows when the use of this important elementary machine was discovered, but it was probably before the use of metals was known or man had learned to clothe himself with anything but the skins of animals.

In the early days, when man lived by hunting and fishing, his implements and weapons were made almost entirely of stone, wood, or the bones of animals. The principle of the lever was applied in some of the weapons of this period, and we may suppose that its discovery was largely accidental.

Perhaps it occurred to an ancient hunter that it would be easier to grasp a round stick than a large smooth stone, and he may have picked up the fallen branch of a tree, one day, and placed the end of it under a stone that he wished to remove from his path, as shown in Fig. 1.

He would then have found that he could easily move a stone in this way that he could not move at all with his unaided hands. Such a discovery he would

FIG. 1

naturally make use of many times. His neighbors—if he happened to be on friendly terms with any of them—and his boys would learn from him, and thus the knowledge would be passed on.

If our ancient hunter had rested his lever on the small stone at the right, placed the lower end of the lever under the large stone and simply rested his weight on the other end, he might have raised the object without lifting at all. This he doubtless soon learned, and another step was taken in mechanical progress.

Thus—largely by accident—the early discoveries in

the realm of mechanics and engineering were made. One discovery led to another, and our race gradually learned to overcome difficulties and obstacles until we have not only largely subdued the earth, but also the sea and the air.

Progress was at first very slow, but after it was learned that there were certain principles that underlay all mechanical movements, these were studied and gradually applied to new uses.

Within the last hundred years, more progress has been made in mechanical science than in all the ages that went before. But if one had predicted, even as late as the beginning of the present century, that within twenty years gasoline-engines would be built both light and powerful enough to carry heavier than air machines to a height of thousands of feet, he would have been called a dreamer. Not only was this accomplished, however, but the performance of the various classes of military airplanes in the great World War put earlier flying records entirely in the shade.

Let us now consider the principle of the lever more carefully, and note some of its familiar applications. Fig. 2 shows several diagrams that illustrate the way in which time and space may be exchanged for power by means of levers.

In these diagrams the heavy lines indicate the first positions of the levers, and the dotted lines show second positions—after force has been applied.

At [*A*], we have the same arrangement as in Fig. 1. ***F*** is the fulcrum, or point about which the lever moves;

W, the point where the weight to be moved rests on the lever, and H, the point where the force is applied. By raising the hands from H_1 to H_2 it will be seen that W_1 is raised to W_2. Now, since F does not move at all, it is evident that any point on the lever between F

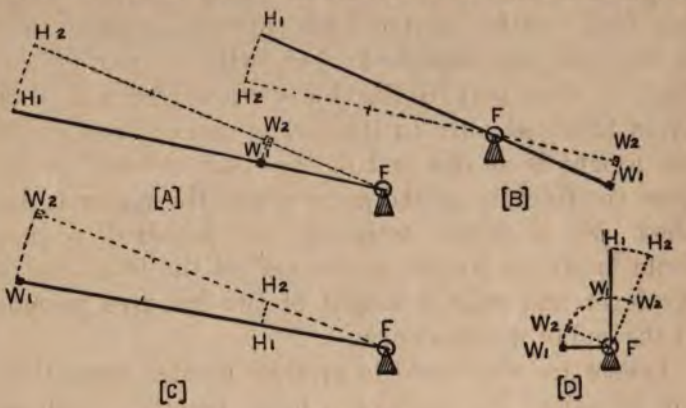

FIG. 2

and H will be moved a distance, always less than the movement at H, proportional to its distance from the fulcrum as compared with the distance from the fulcrum of the point where the force is applied. In other words, if our ancient hunter's hands were applied to the lever three times as far from the fulcrum as the stone was from the fulcrum, he would have needed to raise his hands three times as high as he raised the stone, but he would thus have exerted a force three times as great as though he had lifted on the stone directly with his hands.

In any arrangement of the lever where the applied

force moves a greater distance than the weight, the weight will be moved with proportionately greater force.

[*B*] shows the case where the fulcrum is between the weight and the force. With the same length of lever, less force can be exerted with this arrangement than in the one just described; but, with a lever of this kind, a man may utilize his own weight and thus avoid lifting at all. In the arrangement shown at [*B*] the weight is at one end of the lever one-half as far from the fulcrum as the point where the power is applied. So a person weighing one hundred pounds could apply his weight at the end of the long arm of the lever and raise a weight of two hundred pounds at the end of the short arm.

Levers are often used to produce greater speed than can be gained by applying a force directly. Such an arrangement is shown at [*C*], Fig. 2. Here the fulcrum is at one end of the lever, as in the first case considered, but the points of application of force and weight are reversed. A force applied at *H* can thus be made to lift a light weight quickly at *W*.

A good example of this kind of a lever is the human forearm, where the elbow is the fulcrum and the biceps muscle of the upper arm attached to the large bone of the forearm only an inch or two from the joint, is the moving force. The force exerted by the muscle is thus employed to move the hand quickly, as in throwing a ball.

Levers are not always straight. At [*D*], Fig. 2, is shown a lever with the long and short arm at right

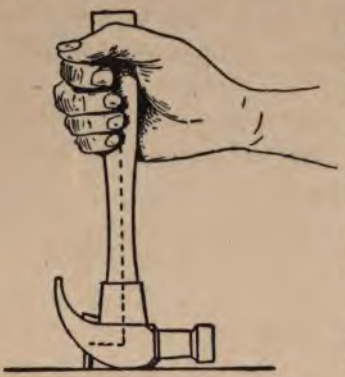

FIG. 3

angles to each other. Otherwise the case is like that shown at [*A*], Fig. 2. A familiar example of this is the ordinary carpenter's hammer, when used in drawing a nail, as shown in Fig. 3.

A pair of metal shears, such as those shown in Fig. 4, act on the same principle as the lever shown at [*B*], Fig. 2. Here the action is the same as though only one of the two parts moved. A large wire can easily be cut in two with one hand by means of such a pair of shears. Of course, the object to be cut should be placed as near the fulcrum as possible. In Fig. 4, the relation between the

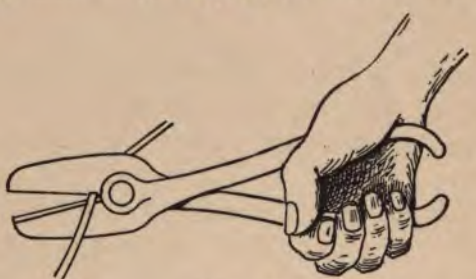

FIG. 4

lengths of long and short arms is about 1 to 10. Ten times as much force can therefore be exerted at the cutting point as that applied by the hand.

Fig. 5 shows a system of levers so arranged that the short arm of one acts upon the long arm of the next, and so on to the lower one which carried a weight at the end of the short arm. If the long arm of each of the levers is four times as long as the short arm, a

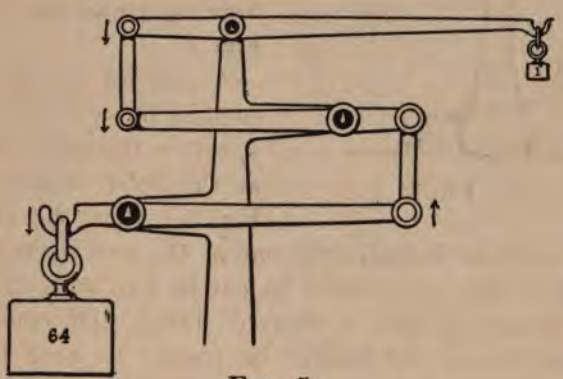

FIG. 5

weight of one pound at the end of the long arm of the upper lever may be made to balance a weight of sixty-four pounds at the end of the short arm of the lower lever.

Weighing scales are constructed on this principle, though the arrangement of levers is not exactly like that shown in Fig. 5.

Cog-wheels, or gears, such as those shown in Fig. 6, act on the principle of the lever. Here a hand wheel is shown attached to a shaft which also carries a small cog-wheel, or pinion. The pinion gears with a larger

cog-wheel on another shaft which is thus made to revolve slowly but with a considerable amount of force. If the positions of the large and small cog-wheels were reversed, the second shaft could be made to move rapidly, but with less force than in the first

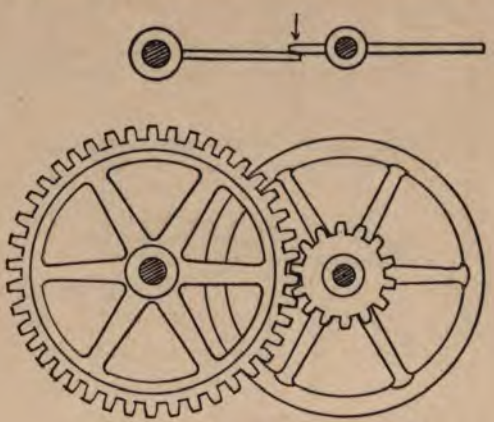

FIG. 6

instance. If we consider the action of one pair of cogs at a time, as shown at the top of Fig. 6, it will be seen that the movement is the same as where one simple lever acts upon another directly, and not by means of connecting links as in Fig. 5.

Cog-wheels provide a means of continuing lever movements and producing circular motions of different velocities and modified force. Systems of gearing, acting on this principle, can be extended indefinitely.

Fig. 7 shows another application of the principle of the lever to what is called a wheel and axle. On a

FIG. 7

single short shaft, a hand wheel and a drum are mounted. Force applied to the rim of the hand wheel can thus be made to lift a heavy weight attached to one end of a cord, or chain, the other end of which is wound around the drum. The dotted lines show that we have here the effect of a simple lever with a long and a short arm on either side of a shaft acting as a fulcrum. In place of the hand wheel a crank may be substituted without any change in the principle of action.

Enough examples of the application of the principle of the lever to modern machine construction might be given to fill this book, but only one other will be mentioned in this connection.

Any one who has closely observed the different classes of locomotives, will have seen that those which are used to pull fast passenger-trains have driving-wheels six feet or more in diameter, while those used for switching freight-cars in railroad yards have several sets of drivers of small diameter. Fig. 8 illustrates how the principle of the lever is here applied. The high drivers and short stroke, of the passenger engine,

are shown above as a means of producing high speed. The low drivers and long stroke, of the switch-engine, are shown below as a means of exerting the great force needed in starting heavy freight-cars, where speed is not so essential.

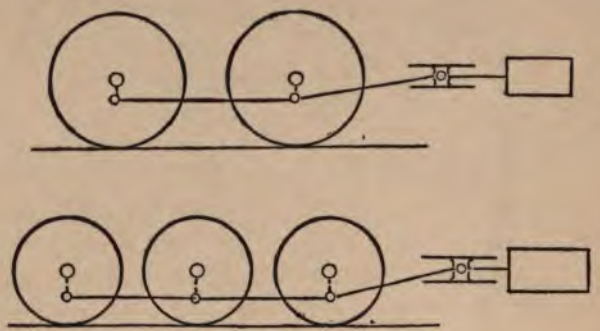

FIG. 8

THE INCLINED PLANE. Another very important mechanical element that has long been known, and which has many applications in modern mechanism, is the inclined plane. It is another convenient means of exchanging time and space for power. Its simplest form is that of a roadway having an upward slope as compared with the horizontal, or water-level. In Egypt, and other ancient countries, this device was used as a means of raising heavy stones to a higher level—as in building the pyramids. The Kings in those early days exercised such complete authority over their subjects, that any number of men that might be needed to build an incline or to pull on a rope were forced to do so. Inclined roadways of sand and dirt

were often made to points where but one or two heavy stones were to be placed. Fig. 9 shows how stones were moved up these inclines by means of a direct

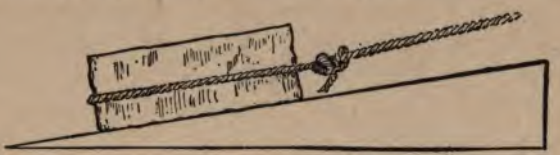

FIG. 9

pull on a long rope. Doubtless they soon learned to place wooden stringers on the roadway and to use rollers, as shown in Fig. 10. Unbelievable as it may seem, that the ancient builders went to the trouble of building long inclined roadways for the purpose of

FIG. 10

moving one or two heavy stones, the writer can state that he has himself observed such means being employed for like purposes in Egypt in this twentieth century. Hundreds of women and children were seen one day at Luxor carrying small baskets of sand on their heads which they were dumping at the end of an inclined embankment which they had built by several days' labor and were extending to a point where

a single stone, resting on two stone pillars, was to be made more secure in an ancient temple. On inquiring why an ordinary wooden staging was not used, the writer was told that wood for staging purposes was very difficult to obtain in Egypt and that sand was abundant and labor cheap. When the work was finished, this staging of sand was all removed by the same slow and laborious process.

In the use of the inclined plane the mechanical advantage is proportional to the ratio of the horizontal to the vertical dimension. In Fig. 10, it is as the relation of *A B* to *B C*, less the friction which is a considerable factor in all applications of the inclined plane.

A familiar example of an application of the inclined plane is the common wedge, Fig. 11, where two inclined planes are placed back to back. Where the driving force is a steel maul, as in this case, friction serves a good purpose in preventing the wedge from rebounding when the maul is being swung for the next stroke.

FIG. 11

Now we come to the consideration of a very common and useful application of the inclined plane, the screw. A screw is an inclined plane wrapped around a cylinder. The diagram at the left in Fig. 12 shows the manner in which a screw is developed from an inclined plane, by winding the plane about a cylinder and afterward cutting away the lower half of

each volute so as to form a raised "thread" that will work in a "nut" of corresponding form. In the diagram the unwound portion is just the length required

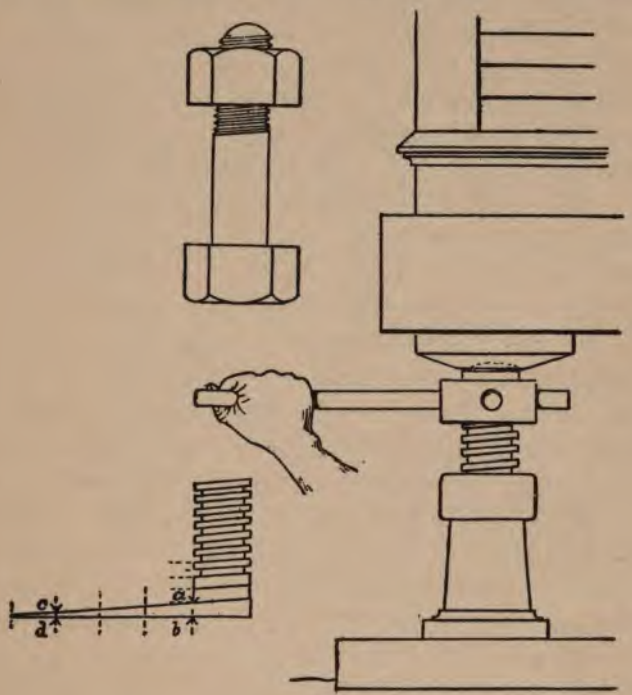

FIG. 12

to wind once around the cylinder, so the distance between the arrow points, *a* and *b*, is the same as that from the top of one thread to the top of the next one, and represents the advance that such a screw would make in the direction of its length when turned one

complete revolution; *c d*, likewise, shows the advance that a quarter turn would produce. By using a long-armed lever for turning the screw, a great difference between the movement of the hand and the advance of the screw results, and a corresponding mechanical advantage may be gained. At the right is shown a common jack-screw, such as is used in raising buildings. The screw works in a nut, in the base, and is turned by means of a lever passed through holes in a projection which is integral, or of one piece, with the screw. The top of the screw has a rounded end which presses against a "screw-plate" on which the body to be lifted rests. In raising buildings, timbers are first placed under the building by cutting away a part of the foundation. Jack-screws are then placed under these timbers, near or far apart according to the weight of the building. If the screws are not placed too far apart, one man can raise a two or three story building by simply going the rounds of the structure and giving each screw a quarter turn. In four trips around the building, which might take him an hour or more in a case where there are many screws under walls and partitions, he would have given each screw a complete turn and raised the whole building perhaps half an inch. If a man could thus raise a building half an inch in an hour, a fifteen-year-old boy could probably do the same thing in two hours, by using a longer lever. Any boy ought to be able to lift the largest building in the town where he lives, provided he has enough jack-screws properly placed and well lubricated.

At the left near the top in Fig. 12, is shown a common machine-bolt, one of the most useful devices ever invented. This has a V thread, instead of a square thread, but is otherwise like the screw just described, though on a smaller scale. The different parts of

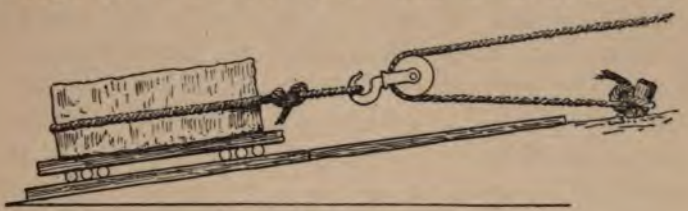

FIG. 13

machines, shafting, steam-pipes, etc., are almost always held together by means of bolts and nuts similar to the one shown.

The screw is a very compact arrangement for exchanging time and space for power. In raising a building half an inch by means of jack-screws, a man would probably move his hands twenty-five feet at each screw. If forty screws were used under the building, he would have moved his hands a thousand feet in raising the entire building one-half an inch. Is not this a good illustration of the exchange of time and space for power?

THE MOVABLE PULLEY. If the ancient builders had used a device like that shown in Fig. 13, where a heavy stone was to be moved only a short distance, they would have found that it would have taken only half as many men to pull the stone as it would by pulling directly, as shown in Fig. 10.

The principle of the movable pulley is rather difficult to explain; but it will be found, in practice, that a pull of one foot on the free end of the rope will move the pulley only half a foot, and thus the force exerted at the hook will be double that exerted at the free end of the rope.

Perhaps the best explanation of the principle is that there are two parts of the rope to be shortened, and, consequently, a pull of one foot on the free end must be divided between the two parts, each of which will be shortened one-half a foot—so the pulley, at the junction of the two parts, will move only this distance. On the principle of exchanging time and space for power, each movable pulley doubles the force exerted at the free end of the rope.

At the right, Fig. 14, is shown a common "tackle and fall" much used for lifting weights, especially on shipboard. In the figure there are four movable pulleys, at the bottom, and four fixed pulleys at the top. The fixed pulleys do not add to the power but are necessary to change the direction of the rope. The four movable pulleys give a mechanical advantage of 16 to 1, as follows: number one gives an advantage of 2 to 1; number two multiplies this result by two, making 4 to 1; number three multiplies this by two, making 8 to 1; and number four multiplies the last result by two, making 16 to 1.

At the left, in Fig. 14, is shown a very simple and useful device called a "chain-block." It consists of one movable pulley and two fixed pulleys above. An endless chain passes around the three pulleys as shown.

The movable pulley hangs in a loop of the chain while one of the supporting branches passes around a fixed pulley above, and the other passes around the other fixed pulley, which is slightly smaller than the first, both being on one axle and moving together. Another long loop is left free to be operated by the hand. In pulling down on one part, as shown in the figure, the right-hand supporting branch is wound over the larger fixed pulley while the other supporting branch is unwound from the smaller one. Clearly, the movable pulley would not be raised at all if the fixed pulleys were of the same size, and the less the difference in the diameters of the two fixed pulleys the greater the force will be that is exerted on the movable pulley. Of course, there will also be an advantage gained by the use of the movable pulley in addition to that gained by the differential device.

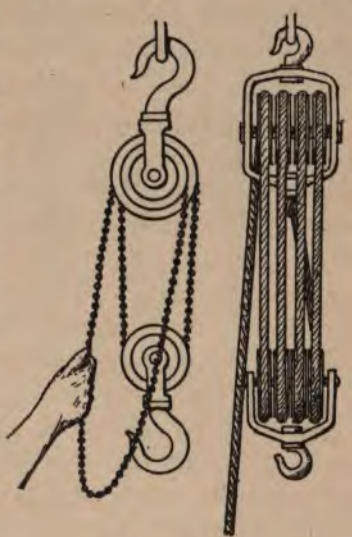

FIG. 14

The limit of the force that can be exerted by such a device, where the difference in diameters of the fixed pulleys is very small, is only limited by the strength of the material that is used in its construction. This device is used a great deal about machine shops, where

heavy weights are to be moved short distances. The free loop is always much longer, in proportion, than could be shown within the limits of the figure.

Cylinders and Pistons. There are one or two other elementary devices that are much used in modern engine construction that should be described in this

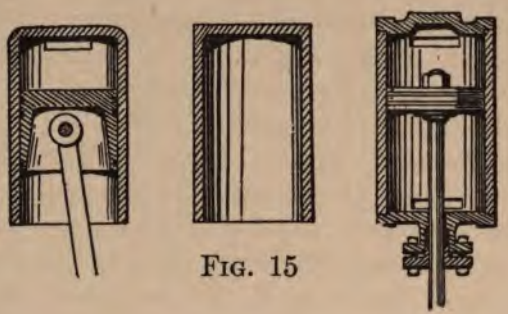

Fig. 15

chapter—though they are not among the so-called "mechanical powers" that were discovered in ancient times. One of these is the hollow cylinder. It is shown in its simplest form in Fig. 15 together with two familiar adaptations. These views are all shown in section, for the sake of clearness.

The closed cylinder is much used for confining liquids and gases; another familiar use is in connection with a moving piston. When so used, it must not only be very strong, but of smooth even bore, so that the moving piston may fit gas or steam tight, while free to move from one end of the cylinder to the other.

At the left, Fig. 15, is shown an ordinary single-acting gas-engine cylinder and piston, with a connect-

ing-rod attached directly to the piston. At the right is shown a common double-acting steam-cylinder fitted with a piston and piston-rod. In both cases the pistons are fitted with packing-rings, to be described more fully in a later chapter. In the case of the steam-cylinder a "stuffing-box" is employed to keep the steam from leaking past the piston-rod. In a single-acting cylinder the gas or steam, confined between the closed end of the cylinder and the piston, in an effort to expand pushes the piston to the bottom of the cylinder and is then allowed to escape, while a crank and fly-wheel connection carry the piston back to its original position. The double-acting cylinder and piston works both ways by steam pressure, and the inertia of the fly-wheel serves to carry the crank past the "dead centre."

Of course, the walls of all steam and gas engine cylinders are subjected to the same pressure as the moving piston, and must, therefore, be made very strong.

VALVES. A valve is a device for controlling the flow of fluids. Fig. 16 shows one of the simplest forms, such as is used in connection with force-pumps. It consists of a conical disk which fits into a seat between two passages connected usually with water or steam pipes. In the figure the valve is shown in its closed position. If water or steam were piped into the right-hand end of this device it would, of course, raise the valve from its seat and pass through with prac-

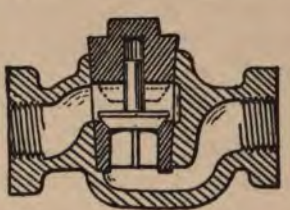

FIG. 16

tically no obstruction. But, if the stream should be suddenly reversed, as in the case of a force-pump, the valve would immediately be forced to its seat, and the passage would be closed. The valve shown in the cut is self-acting, and is called a check-valve. Valves are of many different forms. Some are self-acting, some are operated by hand, and some by the machinery of which they form a part.

CHAPTER II

EARLY STEAM-ENGINES

THE first practical steam-engine was invented by an English mechanic named Newcomen.

In the year 1711, one of these engines was set up at a coal-mine to operate a big pump. As a matter of fact, the Newcomen engines were used *only* for pumping, but an improved engine of somewhat similar construction was afterward used to drive a mill.

Fig. 17 shows the construction of Newcomen's engine. There was a heavy wooden beam, mounted on a pivot at the top of a strong support, one end of which was connected to a pump-rod by means of a short chain, heavily weighted. The other end of the beam was connected, in the same way, with a movable piston working in a steam-cylinder which was open at the top and connected at the bottom with a steam-boiler and a cold-water tank. When the piston was at the top of its stroke, steam was admitted to the cylinder and allowed to flow until it had driven out all the air through the pipe, at the left, the lower end of which was often placed lower than here shown. The steam was then shut off, and water from an elevated tank was admitted through a pipe, as shown. The pressure of the atmosphere on the top of the piston then caused it to descend to the bottom of the cylinder.

This raised the pump-rod and drew water from the mine. The steam-valve was then opened again, and the pressure of the steam, aided by the weights on the pump-rod, caused the piston to rise to the top of the

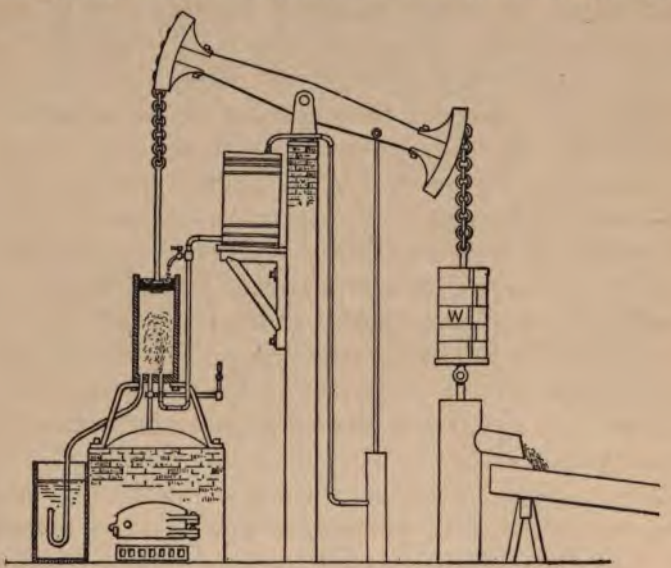

FIG. 17

cylinder. By opening and closing the steam and water valves at proper intervals, this motion was made continuous.

This engine was very wasteful of steam because the cylinder had to be reheated every time steam was admitted, and a great deal of the steam was thus turned to water before it completely filled the cylinder and drove out the air. The cold-water tank was supplied

by means of a small pump worked by the same beam that operated the large one.

Thus the heavy work of raising water from a deep mine was accomplished by simply opening the steam and water valves by hand and keeping a good fire under the boiler.

Now, the story of a bright boy must be told. The opening and closing of the steam and water valves was such light work that it was generally turned over to boys.

Humphrey Potter was so employed at one time, and he immediately put his wits to work to invent a way of making the engine entirely self-acting. After several trials he was able to arrange strings in such a way that the beam in its movements pulled on the handles of the valves and opened and closed them just at the right moment. Rods were soon substituted for strings, and the new arrangement was afterward used on all such engines.

It was found that the opening and closing of the valves could be done in this way much more regularly than it had ever been done by hand, and the speed of the engine was thereby much increased.

Humphrey Potter's invention was the most important improvement on the steam-engine that was made for many years.

The Newcomen engine was soon used wherever flood-water interfered with the working of coal-mines, and its adoption marked one of the greatest advances made in applied mechanics in thousands of years. Here natural forces were made to do very heavy work that had formerly been done entirely by hand.

It might be said that Newcomen's engine was not a true steam-engine, for the piston was forced down entirely by atmospheric pressure. It should be remembered, however, that steam was necessary to force the air out from under the piston and produce a condition that enabled the atmospheric pressure to do its work.

THE ATMOSPHERE. It may not be clear to all readers why the condensation of steam in the cylinder of the Newcomen engine, just described, caused the piston to move to the bottom of the cylinder with sufficient force to raise the heavy weights, pump-rod, and water at the other end of the beam.

It has been stated that it was the pressure of the atmosphere that caused the movement, but how, some may ask, could such a light substance as the air exert such a force? The air which we breathe and move about in so freely seems the lightest thing imaginable, but it presses on every inch of the earth's surface, at sea-level, with a force of fourteen and seven-tenths pounds. This is more than one ton to every square foot. The atmosphere extends about forty-five miles above the surface of the earth, but it is much denser toward the bottom than toward the top, because the lower air has to carry the weight of all that is above it and is thereby compressed. The weight of the air on any given surface exerts pressure, just as truly as the weight of a block of stone exerts pressure on anything on which it may rest. There is this difference, however, between the pressure of fluids, like air and water, and solids like stone. The stone exerts no pres-

sure except downward, while fluids not only exert pressure downward but in other directions as well.

The pressure of the atmosphere on the body of an ordinary-sized man amounts to more than fifteen tons, but it is not felt at all for the reason that the air inside the body equalizes the pressure. Any one who doubts that the atmosphere exerts pressure should experiment with an air-pump by placing his hand over the opening in the plate of the pump while some one exhausts the air from under it. The pressure which he will feel on his hand will be caused by the weight of the atmosphere pressing down where the air has been pumped from underneath.

In a Newcomen engine with a piston 20 inches in diameter, the pressure on the top of the piston would be more than two tons, but, so long as the cylinder is filled with air or steam, that pressure will have no effect on the piston, for the upward pressure exactly balances the downward. In the Newcomen engine the steam pressure never rose much above atmospheric pressure because of the outlet pipe, shown at the left of Fig. 17.

Let us see, now, what happened when the jet of cold water was turned into the steam-filled cylinder. It cooled the contents of the cylinder, of course, and when steam at atmospheric pressure is cooled, it immediately turns to water. But a cubic foot of steam, at atmospheric pressure, turned to water, only occupies a cubic inch of space. Except for a thin layer of water, then, at the bottom of the cylinder, caused by the condensation of steam, and the small amount of cold water admitted from the tank, the cylinder

would have nothing left in it; and the pressure of the air on the top of the piston, being unbalanced, would immediately cause the piston to move downward. The effect was the same as though air had been pumped from under the piston by means of an air-pump. If the steam were all condensed and no air got in between the piston and the cylinder, or in any other way, the pressure on a 20-inch piston, as has been said, would be more than two tons. It is not probable, however, that such good results were attained by means of this rather rough piece of mechanism. In those days turning-lathes for iron were not in use; it is probable that the piston did not fit the cylinder perfectly, and a considerable amount of air must have rushed in that way before the piston reached the bottom. Newcomen had an arrangement for conducting water to the top of the dish-shaped piston partly to cool the piston and partly to form a water seal for the joint between piston and cylinder. Nothing like a complete vacuum was probably produced. If it were only a half vacuum, however, pressure enough would be exerted on a 20-inch piston to raise a weight of one ton at every stroke.

Watt's Engine. Newcomen's engine, as has been said, was very wasteful of steam. James Watt, a Scotch instrument-maker, having some knowledge of science, made a thorough study of the device to see how it could be improved. He discovered that the greatest waste was through condensation of steam when it first entered the cylinder caused by the fact that cold water had been introduced a moment before

to condense the steam of the previous stroke. He decided that it would be better to condense the steam in a separate vessel, so as to avoid cooling the cylinder

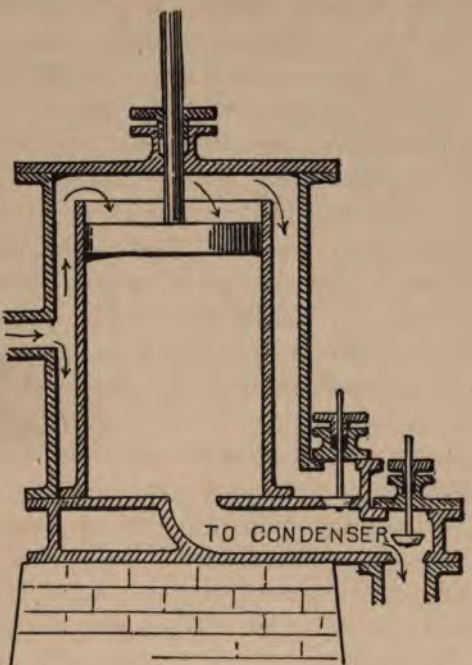

FIG. 18

at every stroke of the engine, and went to work to devise such an arrangement. He decided, too, that something should be done to protect the outside of the cylinder from the cold air. He arrived at the correct conclusion, that a steam-engine is, in reality, a heat-engine, and that the steam must be kept as hot

as possible, and the condenser as cool as possible, in order to have the engine do efficient work. He took another great step in the development of the steam-engine when he made provision for utilizing the expansive force of the steam for moving the piston and no longer depended on atmospheric pressure alone, for the working stroke. Watt's improved cylinder is shown in Fig. 18. The body of the cylinder, in which the piston worked, was, like Newcomen's, open at the top. But there was only one opening in the bottom which led to a passage, in which was a valve, shown at the right. This passage led to a separate condenser. Surrounding this cylinder was another, closed at the top, with a stuffing-box for the piston-rod to pass through. This outside cylinder was large enough to leave two or three inches of space between it and the inner cylinder, and was connected with a steam-supply pipe, shown at the left. On one side, at the bottom, was an equilibrium-valve which connected the space between the two cylinders with the steam passage at the bottom of the cylinder. The use of this will be plain when we come to explain the working of the engine. The condenser, not shown in the figure, was merely another cylinder with a jet of cold water coming into it to which was attached a small pump for removing the water of condensation and any vapor that might remain.

Steam entered, as shown by the arrows, and filled the space between the two cylinders as well as the open end of the inner cylinder. The pressure of the steam, aided by the atmosphere, caused the piston to descend

to the bottom of the cylinder. The steam was then shut off, and the equilibrium-valve opened, the valve leading to the condenser being closed. This caused the

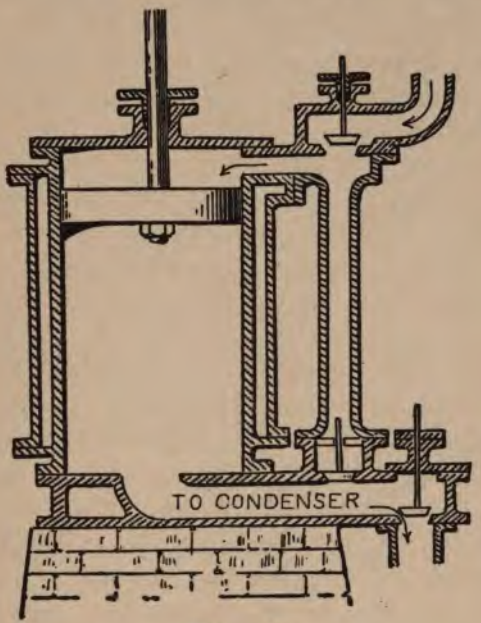

FIG. 19

steam to enter the small space below the piston and equalized the pressure on its two sides. The weights on the pump-rod then caused the piston to rise just as in Newcomen's engine. When the piston reached the top of its stroke, the equilibrium-valve was closed and the one leading to the condenser was opened. The steam below the piston immediately rushed out to fill the

vacuum in the condenser and a condition was produced like that described under Newcomen's engine.

So, it will be seen, Watt's improvement consisted in keeping the working cylinder always hot, the lower part of the cylinder always clear of water and uncondensed steam, and, most important of all, the use of steam as well as atmospheric pressure to move the piston down during the working stroke.

This was such a great improvement over the old Newcomen engine and resulted in such a great saving of fuel that Watt and his partners were kept very busy supplying the demand for these engines.

Very soon Watt made other improvements. He provided a separate entrance to the steam-jacket around the cylinder, and a closed end at the top, as shown in Fig. 19. The operation was similar to that just described. Steam first entered above the piston. When the piston reached the bottom of the stroke, the steam and condenser valves were closed, the equilibrium-valve was opened, the pressure above and below the piston was equalized and the weights on the pump-rod raised the piston. The equilibrium-valve was then closed and the steam and condenser valves opened in preparation for the next stroke.

Watt's next step was to use steam expansively. This was effected by simply closing the steam-valve at the top before the piston had reached the bottom of its stroke. After closing the valve, the steam already in the cylinder expanded and continued to exert pressure on the piston. By closing the valve when the piston was half-way down, only about half as much

steam was used at each stroke as formerly and a great saving of fuel and water was thus effected.

Of course the pressure gradually diminished as the steam expanded, but the amount of work gotten out of a given quantity of steam, and consequently from a given quantity of fuel, was greatly increased.

Watt found that he could cut off the steam-supply when the piston had made from one-quarter to one-third of a stroke and still have enough power to operate the engine. This principle of using the steam expansively has been greatly developed in recent years through the use of compound engines—to be explained farther on.

All the engines that have so far been described were single-acting. That is to say, only the downward stroke produced any power. So long as engines were used solely for pumping, double action was not necessary. But Watt's inventive mind began to work on the problem of turning wheels. By using very heavy fly-wheels, single-acting engines could be made to turn an axle in much the same manner as grindstones and sewing-machines are turned by foot power, but the motion was irregular and not well adapted to most kinds of work. Watt understood the use of the crank as a means of changing up-and-down motion into rotary motion, but a rival of his had secured a patent on this device. So he resorted, at first, to what is called the sun-and-planet motion. A small-toothed wheel was fixed at the end of a connecting-rod, as shown in Fig. 20. The motion of the engine caused this wheel to revolve around another toothed wheel

rigidly connected with the shaft that it was required to turn. The centres of the two wheels were connected by means of a link, as shown in the figure, which was loose on the shaft.

The shaft was by this means caused to make one

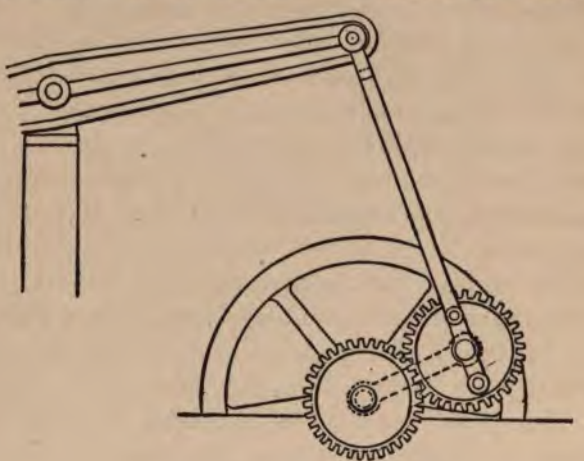

FIG. 20

revolution to every double stroke of the engine. When the patent expired on the crank, Watt adopted it in the form in which it is still used.

By the use of the sun-and-planet motion and a heavy fly-wheel Watt was able to give a rotary motion to a shaft with his single-acting engine, but not much power could be transmitted in that way. His next step was to develop a double-acting engine in which every stroke of the piston, whether up or down, was a power stroke.

This involved some changes in his valve arrangements, but he succeeded in accomplishing his object without adding greatly to the cost of his engine. In his double-acting engine, steam was admitted first on one side of the piston and then on the other. While steam was acting on one side of the piston, the opposite end of the cylinder was exhausting into the condenser, so the full force of atmospheric pressure was utilized on the up stroke as well as on the down stroke.

The chain connection which Watt, as well as Newcomen, used in his earliest engines, between the piston and working-beam, could not be used in connection with a double-acting piston. The ends of the working-beam, of course, moved in arcs of circles and chain connections over curved guides, such as those shown in Fig. 17, served well where the work of the engine was all done on the down stroke. The piston-rod, shown in Figs. 18 and 19, could be used to take the push of the piston on the upward stroke, but could not be connected directly with the working-beam because of its swaying motion. Watt finally succeeded in inventing a parallel motion device, shown in Fig. 21, which counteracted the swaying motion of the working-beam, and caused the upper end of the piston-rod to move in a straight line.

It consisted of a system of rods joined together by means of movable joints, as shown. One of these rods was connected with a bracket fixed to a wall or other firm support. This rod had two branches, so that the piston-rod could move between them. As the working-beam moved upward from its central position,

it swayed the upper end of the short connecting-rod toward the left, but the rod that was hinged to the wall bracket was at the same time acting in the opposite

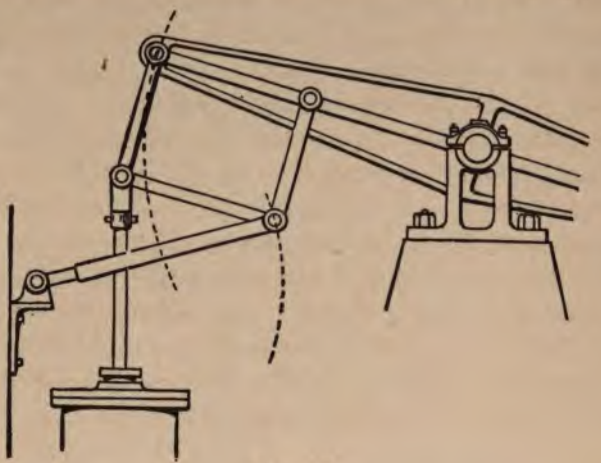

FIG. 21

direction. By means of the other rods these two contrary movements were made to equalize each other.

Watt was more fortunate than many inventors have been in securing a partner. A manufacturer named Boulton furnished money and business experience, while Watt continued to devote his attention to perfecting his inventions and superintending their construction. The demand for engines was so great that Boulton and Watt were obliged to increase the capacity of their plant at many different times, and a profitable business was carried on by them for many years.

Watt's double-acting steam-engine was the fore-

runner of the modern reciprocating steam-engine and differed from it only in minor details.

Ever since this great inventor showed the way the heaviest work of all civilized countries has been performed by natural forces, and great burdens have been lifted from human shoulders.

Not only has the steam-engine lightened the labors of countless thousands of men by making it possible to apply a great natural force to the performance of tasks once done by hand; but, by making it easy to reproduce many articles from a single pattern, it has stimulated production and multiplied the output of hundreds of articles of daily use. Many things that were formerly considered luxuries, to be enjoyed only by the rich, are now so cheaply manufactured by power that they may be enjoyed by all.

CHAPTER III

STEAM-BOILERS, FURNACES, AND CONNECTIONS

BEFORE proceeding to the description of modern engines, something should be said about methods of generating steam. Steam-boilers and furnaces are as important, in their way, as engines and require as much care in design and manufacture.

Watt employed steam pressures of only about ten pounds above that of the atmosphere, and Newcomen used even lower pressures, so their boilers did not need to be nearly as strong as modern boilers which often carry steam at over two hundred pounds' pressure per square inch. Newcomen used a kettle-shaped boiler, the lower part of which was made of copper, and the upper part of lead. Copper stands fire even better than iron or steel, and it is still used about locomotive fire-boxes; but it has too little tensile strength for the shells of large modern boilers. Lead and other soft metals, of course, cannot be used where steam pressure is to be carried much above atmospheric pressure.

Boilers are usually of cylindrical form, because this is not only a good shape to withstand internal pressure but one that lends itself to easy construction. A spherical shape would be even better for withstanding the pressure of steam, but this is a difficult shape to make and one that does not allow of the use of flues and tubes for increasing the heating surface. A boiler that had no heating surface besides its outer shell

would not make steam fast enough for running an engine that had much work to do. Various devices used for increasing the heating surface of modern boilers will be described farther on. The heating surface of a boiler is that which separates the water from the flame and hot gases that arise from the burning of fuel, usually coal, under or within the lower part of the boiler.

This brings us to a consideration of furnaces and fire-boxes.

FURNACES. Heat is the result of chemical action which takes place when the oxygen of the air unites with the carbon and other combustible elements of fuel, so an important consideration in the design of a furnace is a proper arrangement for supplying air.

In Fig. 22, three kinds of fires are shown. At the left is shown a fire such as is often built in the open air. Here the fuel is entirely surrounded by free air which flows in from all directions as the fuel is slowly consumed and the resulting hot gases rise. The hot gases rise because they are lighter than the surrounding air, and this tends to produce a vacuum over the fire and the surrounding air rushes in to fill it. Whenever air comes in contact with very hot fuel it gives up its oxygen, and this keeps up the fire. Because of the ascending current over an open fire, the incoming air moves in directions indicated in the figure by the arrows, and very little of it really comes in contact with the fuel.

At *b*, we have a section of an ordinary fireplace connected with a chimney. The chimney plays an important part in keeping up the fire, as we shall see.

The fuel is supported on a grate. After such a fire

is once started, the hot gases rush up the chimney and the air which is drawn in comes only through the opening at the front. A part of this incoming air passes

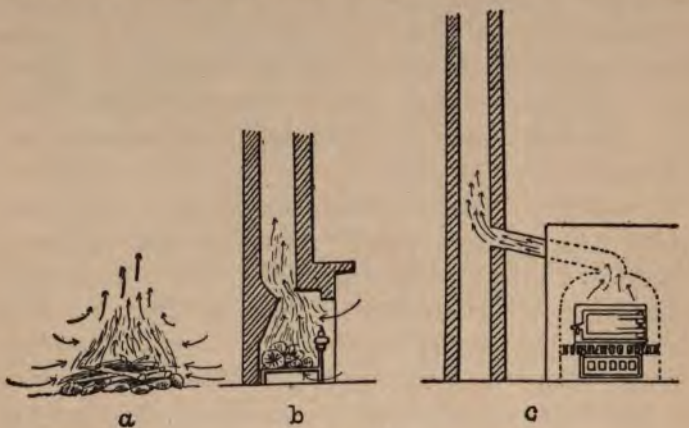

FIG. 22

under the grate and is brought in close contact with the fuel as it passes through. Such a fire will burn much better than the one shown at *a*, not only because a part of the incoming air passes directly through the fuel, but for the further reason that the ascending column of hot gases is confined to a chimney which keeps it away from the surrounding cold air which would otherwise mix with it and cool it. This rapidly ascending column of hot gases produces a draft, which brings more air in contact with the fuel and produces more heat. Only the air which comes in actual contact with the fuel helps to keep up the fire. That which rushes in through the upper part of the fireplace opening only tends to cool the ascending gases

and to check the draft. If a "blower," or cover, is placed over the front opening so that no air can enter except that which comes through the fire from under the grate, the draft will be greatly increased and the fire will burn much more briskly. At *c* an ordinary closed furnace with an elevated grate is shown, where all the air that feeds the fire is compelled to pass between the grate-bars, and all the hot gases pass through a pipe directly into a tall chimney. When the fuel door is closed, such a furnace, with proper fuel, makes a very hot fire. The higher the chimney the better the draft will be, because a longer column of hot ascending gas is thus produced. This is the arrangement ordinarily used for producing a fire under a steam-boiler. In some cases, where very tall chimneys are not practicable, blowing-machines are used for forcing air directly under the grate. Another device for increasing the draft, used on locomotives, is to exhaust the steam from the engine through a short vertical pipe at the bottom of the smoke-stack. The rushing column of hot steam draws the hot gases with it, and this causes air to rush between the grate-bars and through the fuel.

But all these various devices for producing a hot fire are of no use unless some effective means be employed to impart the heat to the water in the boiler, and thus generate steam for the engine. All the heat that escapes up the chimney is wasted. This is the greatest drawback to the steam-engine as a means of converting heat into useful work.

Vertical Boilers. As we now consider the various forms of steam-boilers we shall see how they are

planned to get the greatest possible amount of heat from a given quantity of fuel.

Fig. 23 shows one of the simplest forms of the steam-boiler, such as is used in connection with hoisting-engines. It consists of a cylindrical shell standing on one end, with a furnace below and a smoke-stack immediately above it. The furnace, which has an elevated grate, consists of a cylindrical shell of smaller diameter than the boiler, connected with the smoke-stack by means of a number of vertical tubes, the lower ends of which pass through the top of the furnace, or fire-box, and the upper ends of which pass through the top end of the boiler. It will be noted that the fire-box is entirely surrounded by the water in the boiler

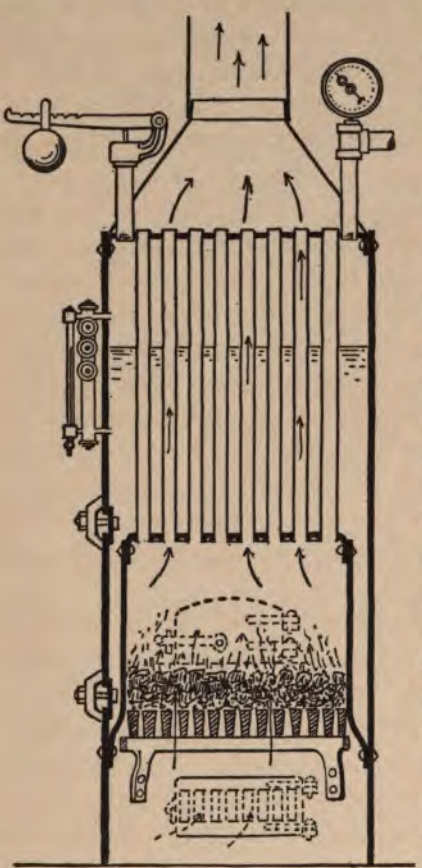

FIG. 23

and that the tubes greatly increase the surface which separates the flame and hot gases from the water.

The heating surface of a boiler should bear a certain fixed relation to the grate surface, or bottom of the fire. The ash pit, in this case, is merely an extension of the boiler-shell. The grate-bars are supported on a ring bolted to the shell. An ash-door, below the grate, provided with a gridiron-shaped damper, is the only means by which air is conducted to the fuel.

The hot gases, of course, rush up the tubes to the smoke-stack. This draws air between the grate-bars and directly through the fuel. The fire-door, shown above the grate in dotted lines, also serves as a check to the draft—whenever the engine is not running and the fire-door is left open. The tubes are made of much thinner metal than the rest of the boiler because of their small size and the fact that the pressure on them is from the outside inward. Fastened, as they are, to both the crown sheet of the fire-box and the top end of the boiler, they serve to greatly strengthen both of these parts.

A small boiler of this description is usually made of a single sheet of metal bent into cylindrical shape, with fire-box and upper end sheet riveted to it, as shown. The top sheets of both fire-box and boiler are first made dish-shaped, and holes are afterward cut for the tubes to pass through. The lower end of the smaller cylinder which forms the fire-box, is expanded and bolted to the boiler-shell.

Boilers of this shape, when made of metal of the

proper grade and thickness, will withstand a pressure of several hundred pounds per square inch of surface.

When steam is raised every part of the boiler, firebox, and tubes, is subjected to the same pressure whether above or below the water line and the greatest care has to be taken to have all joints securely riveted and steam and water tight. Every boiler has to be fitted with certain accessories and connections which will now be pointed out. At the right and top of the boiler, Fig. 23, is shown a steam-pipe connection, which leads to the engine, and a steam-gauge attached to the pipe near the boiler for measuring the pressure. The gauge is a very important accessory and should be frequently tested to see that it is in good working order. Its construction will be described later. On the other side is shown a safety-valve which consists of a conical disk resting in an opening of corresponding shape connected with the boiler. Here it is connected by means of a short steam-pipe because of the cone-shaped smoke-box which covers the top end of the boiler. A short pin is fitted to the top side of the safety-valve and this presses against the under side of a lever that is weighted down by a movable ball which can be set in different notches according to the pressure at which the boiler is designed to blow off, which is usually far below the pressure that the boiler will stand. This device is a necessary safeguard with which every boiler must be supplied.

Little if any less important than the safety-valve is the water-gauge, shown at the left just below the safety-

valve, Fig. 23. It consists of a stout glass tube connected with two short pipes one of which enters the boiler-shell above the proper water level and the other below. Water will stand in the glass tube at the same level as in the boiler and the gauge should be placed where it can be plainly seen by the man in charge. Connected with the same pipes as the glass tube is usually a larger tube of metal which stands parallel with the water-glass. Three gauge-cocks are attached to this tube, one at the proper water level, one above and one below. These should be opened periodically to make sure that there is no stoppage in the connections of the water-glass. A pet-cock is attached to the lower end of the water-glass so that steam may be blown through it occasionally to keep it clear.

Water always contains more or less sediment which accumulates in boilers as the water is evaporated. Hand-holes are therefore provided near points where the deposit is most likely to occur. In Fig. 23, one is shown near the bottom of the boiler and another just above the level of the crown sheet of the fire-box. The hole in the shell of the boiler is large enough for a man to put his arm through. This is covered by an oval plate which is held in place by means of a bolt passed through a hole in the plate and another in a "spanner." Some sort of packing is always necessary both between the plate and shell and around the bolt-hole in the middle of the plate. Manholes, sufficiently large to allow a man to pass through when the boiler is in need of repairs or a thorough cleaning, are placed in all large boilers.

THE HORIZONTAL TUBULAR BOILER. Fig. 24 shows a horizontal tubular boiler, in its usual setting. The boiler consists of a cylindrical steel shell with flat ends and a large number of horizontal tubes as shown on the

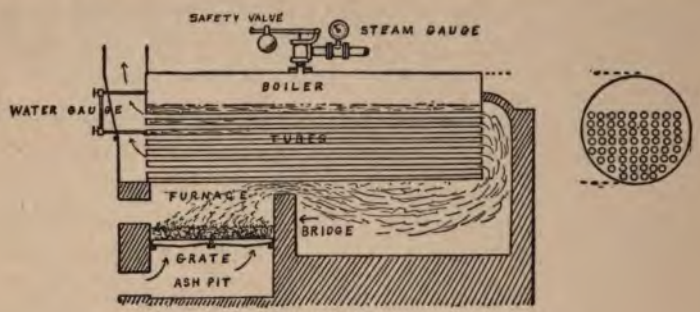

FIG. 24

end view, at the right. By means of heavy brackets bolted to the shell the boiler is supported on brick walls the same distance apart as the diameter of the boiler. A wall in the rear is located a foot or more back of the end of the boiler, and an arch is turned from the top of the wall against the end-plate, just above the top line of tubes. The furnace under the front end of the boiler has a "bridge wall" at the back, which is built up on a curve so as to come within a few inches of the shell of the boiler. At the front end of the boiler, above the level of the furnace, there is a space called the smoke-box with an iron front connecting with a pipe leading directly to a chimney or smoke-stack. The water-gauge has long connections so as to bring the glass in front of the smoke-box where it can readily

be seen. The steam-gauge and safety-valve are usually connected with the boiler end of the steam-pipe leading to the engine. Here the whole lower half of the boiler-shell is in close contact with the fire, and the hot gases pass over the bridge and enter the tubes at the rear end, thence through the tubes to the smoke-box and out the chimney.

The space between the bridge and the rear end of the boiler serves as a combustion-chamber where the half-burned gases that pass over the bridge are more completely burned. This is a more efficient boiler than that shown in Fig. 23 for the reason that the hot gases have a less direct outlet and are held longer in contact with the heating surface. The fire is controlled by means of dampers in the fire and ash-pit doors—not shown in the figure.

This boiler is of simple construction and is much used in heating plants, as well as for generating steam for engines. Boilers like that shown in Fig. 24 are often set in "batteries" only a foot or two apart. Sometimes the whole battery of several different boilers is surrounded by a single set of brick walls. Each boiler should have an independent furnace and steam connections, so that it can be shut off from the others when in need of repairs, or when less steam is needed than the whole battery can supply.

The Locomotive Boiler. Fig. 25 shows the essential parts of a locomotive boiler. It consists of a shell of general cylindrical form, but often enlarged at the back, with a self-contained fire-box at the rear end, connected by means of a great number of small tubes,

with a smoke-box at the other end. A short smoke-stack is attached to the top of the cylindrical smoke-box, and, immediately underneath, is an inverted funnel with its large end over the exhaust-pipe of the

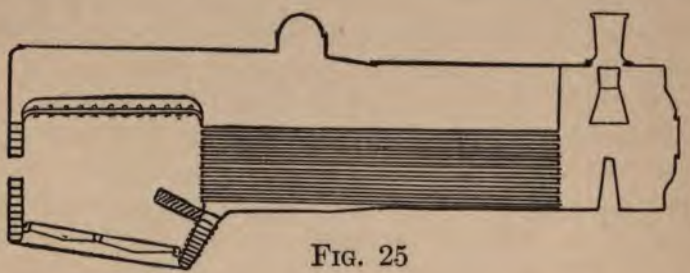

FIG. 25

engine. This is a very good form of boiler inasmuch as the fire-box is entirely surrounded by water—except at the bottom—and the tubes are very close together. The fire-box has flat surfaces on all sides, and has to be strengthened by means of stay-bolts and girders, which will be more fully described hereafter.

The locomotive type of boiler is often used for stationary engines and for heating purposes. It requires no brick setting and can be easily erected. In Fig. 25 a "steam-dome" is shown at the top of the boiler. Most boilers are provided with this device for collecting the hottest and dryest steam before it is piped to the engine. In locomotives, a steam-pipe inside the boiler connects the steam-dome with the cylinders.

MARINE BOILERS. Fig. 26 shows the type of boiler that is used on ocean liners. It consists of a cylinder

of large diameter and of comparatively short axis, inside of which are several independent furnaces, combustion-chambers, and sets of tubes. The left-hand view is a section through the axis of the boiler showing one set of fire-box, tubes, and combustion-chamber. The other view shows a cross-section of the tubes and furnaces, at the right of the centre line, and an end view of the left half of the boiler. It will be seen that the furnaces are of a general cylindrical shape, but corrugated so as to allow for expansion when heated. Just below the middle line of each furnace there are supports for a grate. Behind the grate is a low bridge wall, of fire-brick, supported on a steel partition which forms the back of the ash pit. Behind the bridge and ash pit the furnace flue joins with a combustion-chamber which rises to the height of the top row of tubes. The combustion-chamber is connected with the front of the boiler by means of tubes. The tubes discharge into "uptakes" which connect with the smoke-stack. The two outside sets of furnaces and connections are elevated to conform to the shape of the boiler, as will be seen in the right-hand view. The outside walls of the outer combustion-chambers are curved to conform to the shape of the boiler, but all the other walls are made of flat sheets of metal and consequently have to be stayed and braced in the manner shown in the figure. There are short stay-bolts between the flat walls of the combustion-chambers that face each other, and other stay-bolts connecting the curved sides with the outer shell of the boiler. The flat sheets that form the tops of the combustion-chambers are reinforced by means of

girders bolted to the tops of the sheets. The great flat ends of the boilers are connected by means of long stay-rods running the whole length of the boiler. All of these stays and braces are necessary to prevent the flat surfaces from collapsing. It can easily be seen that this is a very complicated and expensive boiler to make. It has the advantages, however, of being very compact and of saving fuel, which are very important considerations on shipboard. The boiler shown in Fig. 26 is what is called a "single ender." Most of the boilers used on the great liners are double-ended—like two of the kind shown in Fig. 26 placed back to back. "Double enders" usually have four sets of furnaces, combustion-chambers, and tubes, at each end.

The Cunard liner *Aquitania* has twenty-one double-ended boilers 22 feet long and 17 feet and 8 inches in diameter. Each of these boilers has eight furnaces, four at each end. Each furnace requires a separate stoker—one hundred and sixty-eight in all. About a thousand tons of coal are burned in a day's run. The outer shells of the *Aquitania's* boilers are more than 1½ inches in thickness. The end-plates are not quite so thick, but are stayed together by rods 2⅞ inches in diameter. It is said that if the tubes contained in the twenty-one boilers of the *Aquitania* were placed end to end, they would reach 54 miles.

Boilers in steamships are placed as low in the hulls as possible, and are grouped in such a way as to leave room for stoking and cleaning. The boilers of the *Aquitania* are set in batteries of three, side by side,

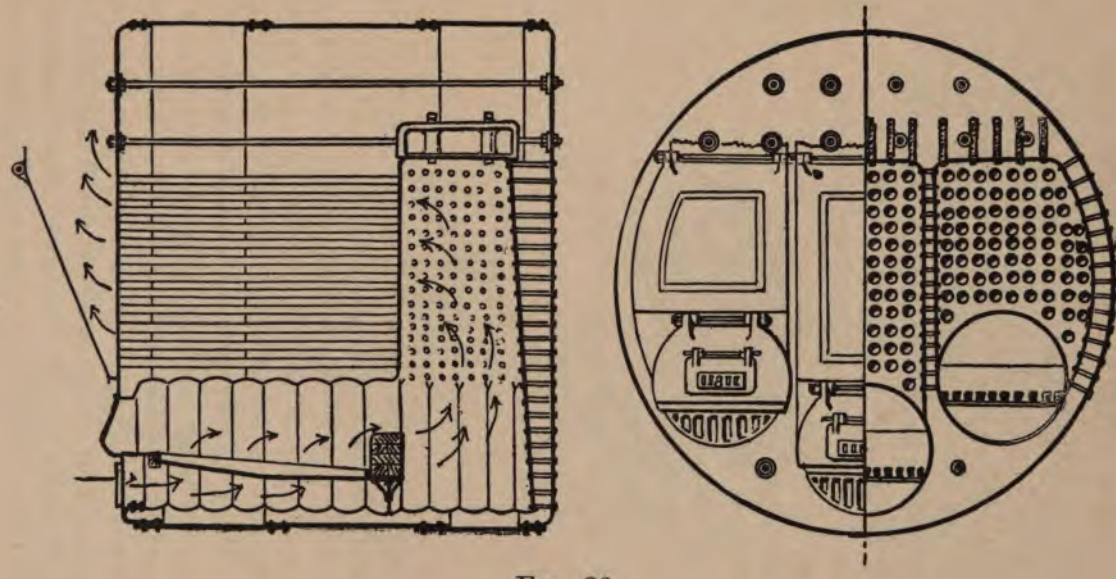

FIG. 26

with stoke-holes between each battery. Usually there are two or more funnels on a liner, to which the furnaces are connected by means of steel connections called uptakes.

Forced drafts are sometimes produced by pumping air under pressure into the stoke-holes, whence it can

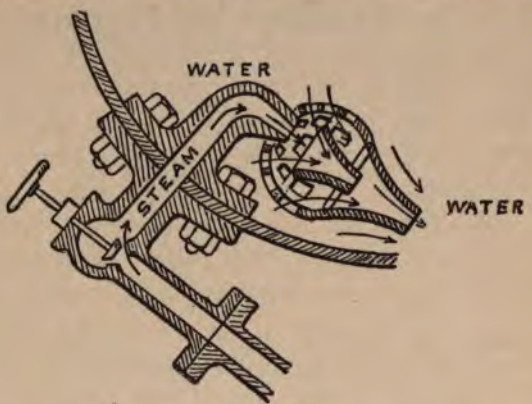

FIG. 27

only escape through the grates and furnaces of the boilers into the funnels.

Steam-boilers should always be so designed as to provide for good circulation, but it is sometimes necessary to arrange special apparatus for this purpose. Fig. 27 shows an attachment for marine boilers whereby steam is admitted through a covered nozzle which passes through an opening near the bottom of the boiler. Immediately in front of the nozzle, inside the boiler, is an attachment through which the water is drawn by the current of steam and moved rapidly around the boiler. This is used, occasionally,

to stir up any sediment that may have been deposited at the bottom of the boiler.

Fig. 28 shows how the long stay-rods that are used in marine boilers are attached to the end sheets. Fifteen or twenty of these are used in each boiler of a big liner, and they are sometimes 3 inches in diameter.

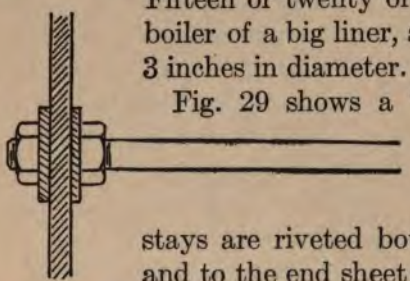

FIG. 28

Fig. 29 shows a "gusset stay" that is sometimes used to support the flat ends of boilers. These stays are riveted both to the outside shell and to the end sheet to be supported.

Where flat surfaces, like the tops of fire-boxes and combustion-chambers cannot be stayed to other parts of the boiler, girders are used like those shown in Fig. 26. These girders are attached to the plates by bolts and prevent the plates from being bent inward by the pressure of the steam.

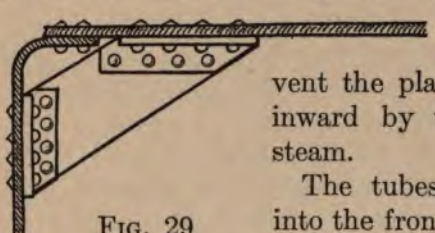

FIG. 29

The tubes, which are headed into the front plates of the boiler and the combustion-chamber, act also as stays for the support of these plates; but stay-rods have to be used between the furnaces, as shown at the right in Fig. 26.

Cylindrical boilers, such as have been described, are made of steel plates bent to the required shape and joined as shown in Figs. 30 and 31. Short

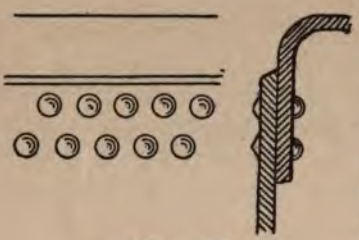

FIG. 30

steel rivets are placed in drilled holes and headed up on the outside. The rivets contract slightly as they cool and this draws the plates closely together. Fig. 30 shows a double-riveted lap joint, and Fig. 31 a butt-joint. In the butt-joint two plates, slightly thinner than the boiler-shell, are lapped over the joint, and the rivets are then passed through all three pieces.

After a boiler has been riveted together, all the joints have to be "calked" to make them perfectly water and steam tight. This is done by "heading" the outside edge with a square-nosed tool and hammer, as shown in Fig. 32.

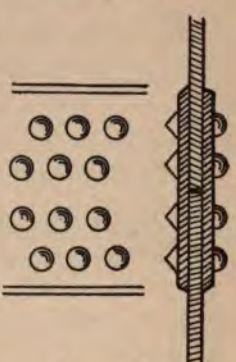

FIG. 31

THE WATER-TUBE BOILER. Another style of boiler, quite different from those that have been mentioned, remains to be described. It is the water-tube boiler. Here the heating surface is made up principally of tubes, so arranged that water may freely circulate through them while the flames and hot gases are made to circulate around and between them. Fig. 33 shows the main features of a type of water-tube boiler that is much used at the present day.

A long cylinder is supported at a considerable height

above the grate, while the space between is occupied with piping, and guiding partitions for controlling the movement of the hot gases. Attached to the under side of the cylinder are two inclined legs which connect

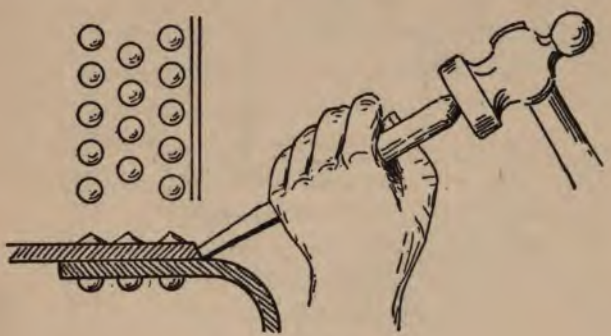

FIG. 32

with headers that support the main water-tubes, in an inclined position. The front parts of the tubes are supported directly over the grate while the other ends are connected with a mud-drum near the bottom of the combustion-chamber. Water fills the tubes, headers, legs, and the lower third of the cylinder. As the water in the tubes is heated it expands and rises through the front headers and enters the front part of the cylinder. The cooler water in the cylinder descends the leg in the rear, and follows the ascending current until it becomes heated in turn and rises into the cylinder. Perfect circulation is thus produced and very soon the water becomes so heated that it issues into the cylinder

in the form of steam, which collects in the upper part of the cylinder as it would in an ordinary boiler.

It will be seen, by Fig. 33, that the hot gases, after

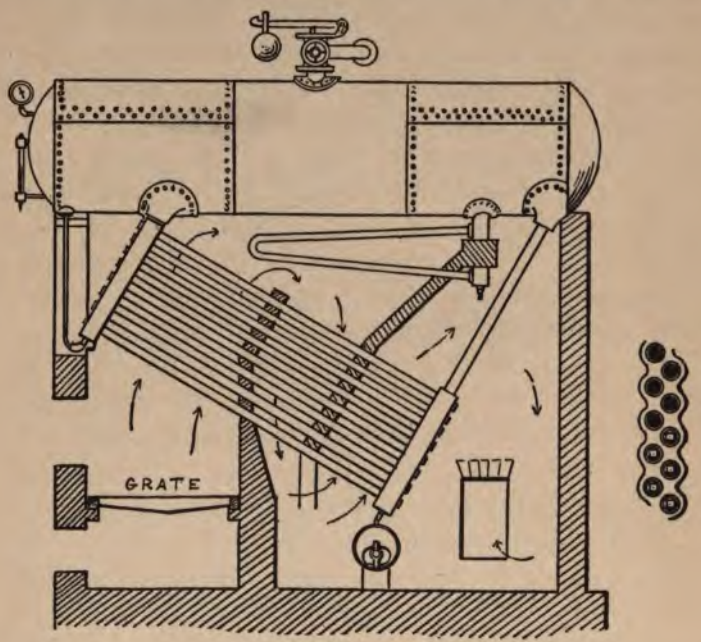

FIG. 33

rising between the water-tubes, are made to descend and rise again between the back ends of the tubes before they can escape through the opening into the smoke-stack. This is about the best possible arrangement for extracting the heat from fuel and imparting it to water in a boiler. The hottest water is always toward the top of the inclined tubes, directly over the hottest part of the fire, while the somewhat cooler

gases are brought into contact with the lower part of the tubes which contain the coolest water in the boiler.

The tubes are not placed in vertical rows but are "staggered" as shown in the end view at the extreme right, Fig. 33. The hot gas is thus obliged to take a zigzag course which brings it into contact with every tube. On the opposite side of the headers from that in which the tubes are connected, there are plugs which can be removed when it is necessary to clean or repair any of the tubes. The view at the right shows five open holes, and five closed with plugs. In case any tube becomes leaky or blows out, it can be plugged at the header. The boiler can then be used as before, with its heating surface only slightly reduced.

The hairpin-shaped tube near the top of the combustion-chamber is a "superheater" for drying out the steam and adding heat to it. Superheated steam is more effective than "saturated" steam in an engine that is designed to use steam expansively.

The superheater connection passes through the bottom of the large cylinder and opens into the steam space near the top. It will be seen that the opening into the smoke-stack is near the bottom of the combustion-chamber, where the gases naturally fall after imparting their heat to the boiler.

Travelling grates are often used with this type of boiler. By means of this device, one or two firemen are able to keep a large battery of boilers supplied with fuel, where hand-firing would require a large crew of men. Not only does the travelling grate save labor in firing, but it makes possible the use of inferior grades of fuel with the least possible amount of

smoke. It consists of a large number of small grate-bars hinged together in the form of a chain which runs over revolving drums—one at the back of the furnace and one outside of the fire-door. These drums are made to revolve, very slowly, so that the grate will advance from the front to the back of the furnace and then be brought back, like the under side of a belt. Fine coal is fed into the front end of the grate through hoppers that are kept filled by machinery. As the fuel slowly advances into the fire it becomes gradually heated, and is finally burned to an ash before it reaches the back of the furnace. In this way, nearly the full heating value of the fuel is made use of.

The black smoke which appears whenever a large quantity of fresh coal is added to a fire, is composed largely of fine unburned fuel, which is of course wasted. In hand-firing it is not only necessary to throw coal on in shovels full, but the fire-door must be held open while this is done. The combined effect of the cold fresh fuel and the inrush of air through the fire-door, is to check the fire for a few moments, and thus to add another hindrance to the proper working of the steam-generator. By the use of the travelling grate the fuel opening can be kept closed down to a space just large enough to admit the travelling grate and its thin layer of fuel.

Water-tube boilers that are fitted with travelling grates have furnaces about twice as deep in proportion as that shown in Fig. 23. This necessitates the use of longer water-tubes set at a flatter angle than that shown in the figure.

Travelling grates are sometimes called chain-grates, and they are nearly always mounted on trucks, so that the whole device can be drawn out of the furnace, whenever it is necessary to make repairs.

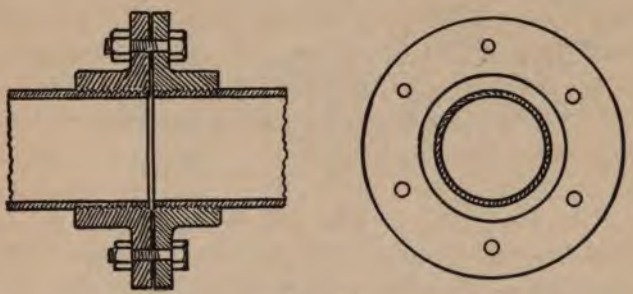

FIG. 34

STEAM-FITTINGS. A great many steam and water pipes are necessary about steam-boilers and engines, and these are generally made up of short lengths which must fit together steam-tight. Fig. 34 shows the form of joint generally used to connect large steam-pipes. It consists of two flanged rings of cast or malleable iron into which the ends of the steam-pipes are screwed. The faces of the flanges, which have previously been turned in a lathe, are then brought together, with a thin ring of asbestos or other packing between, and bolted as shown in the figure.

Whenever it is desired to change the direction of a line of piping, "elbows" of various angles are used. These and other forms of steam-fittings are connected by means of flanges and bolts like those shown in Fig. 34.

Small pipes and fittings are joined by merely screw-

ing the parts together as shown in Fig. 35 where various forms of fittings are grouped together.

From left to right the various fittings shown in Fig.

FIG. 35

35 are named—elbow, short nipple, tee, long nipple, union, nipple, coupling, nipple, forty-five degree elbow and plug.

The larger the diameter of a pipe or cylinder subjected to internal pressure, the greater its thickness needs to be. In Fig. 36 two cylinders are shown, one of which has a diameter four times as great as the other. If each of these cylinders is subjected to steam pressure, of say one hundred pounds to the square inch, the pressure will, of course, be exerted outward from the centre; but, so far as it tends to rupture the cylinder along lines parallel to the axis, it will act as indicated by the dotted arrows—at right angles to the diameter indicated. The large cylinder

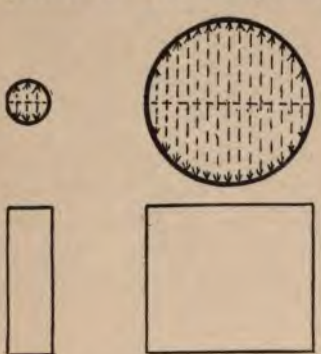

FIG. 36

will have to withstand four times as much stress along a given length—on the two sides—as the smaller one, so the thickness will need to be four times as great. The boilers of ocean liners are often more than an inch

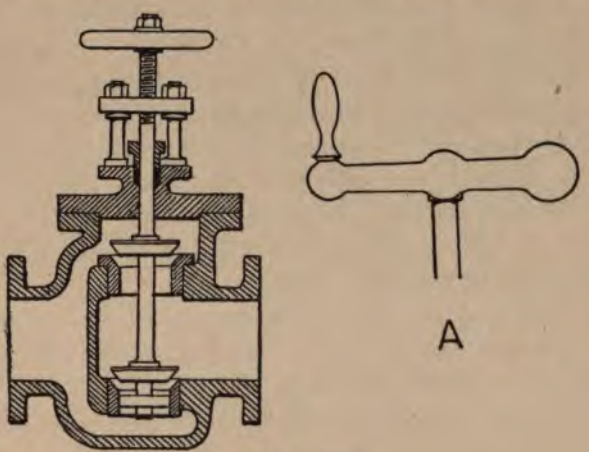

FIG. 37

and a half in thickness, but a good sound half-inch steam-pipe, connected with one of them, would not need to be one-sixteenth of an inch in thickness to withstand the same pressure.

In order to control the flow of steam from the boiler to the engine, various forms of valves are used. Large shut-off valves are usually of the balanced type, for the reason that this form can be more easily operated against heavy steam pressure. An ordinary valve 4 inches in diameter opening against a steam pressure of one hundred and eighty pounds to the square inch

would be pressed against its seat with a force equal to a weight of one ton. Fig. 37 shows a balanced valve that can be easily operated against the highest steam pressure. It consists of two conical disks connected with a single stem terminating in a screw and hand wheel. The disks, which close against openings of corresponding shape, operate one *with* and one *against* the pressure, so that one balances the other. Let us suppose that the left end of the valve-casing, shown in Fig. 37, is connected with the boiler and the right-hand end with the engine. When the valve is closed, steam will press against the top of the upper disk and against the bottom of the lower one.

If these surfaces are of the same size, the valve will be perfectly balanced. If the top disk is slightly larger, as is usually the case, the valve will have to be operated against a slight resistance due to the excess of pressure on the upper disk.

Sometimes a balanced hand crank, like that shown in Fig. 37, *A*, is used instead of a hand wheel for operating a shut-off valve.

CHAPTER IV

RECIPROCATING ENGINES

After studying, as we have, the construction of Watt's condensing engines, a common horizontal high-pressure engine, like that shown in Fig. 38, looks very simple. But there are certain modern features that have not yet been explained. Newcomen and Watt both employed a working-beam, as we have seen, to transmit the motion of the piston to the pump-rod in their big pumping-engines. Watt continued to use this device in connection with mill-engines. The more compact arrangement shown in Fig. 38 was later adopted for engines of moderate size.

Attached to one end of a strong rigid base are a double-acting cylinder, piston, and steam-chest; at the other end are a horizontal shaft, crank, eccentric, fly-wheel, and driving pulley. Sometimes the two parts last mentioned are combined in one. Between the cylinder and shaft are the necessary rods and guides for the transmission of power. In this case, the steam-chest and slide-valve, which receive and distribute the steam as it comes from the boiler first to one side of the piston and then to the other, are shown at the top of the cylinder. This arrangement allows us to see all of the essential parts in one view. The steam-chest is bolted to a plane surface on the top side of the cylinder. In this surface there are three oblong

openings, as shown at *A* above. The wider one, in the middle, connects with a passage leading to the exhaust-pipe and the other two open into passages leading to the two ends of the cylinder. The D-shaped slide-valve is long and wide enough to cover all three open-

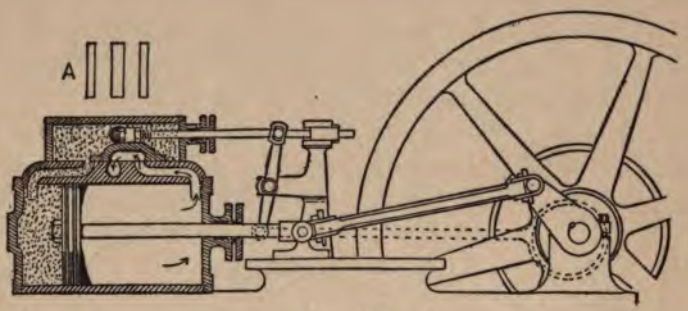

FIG. 38

ings when in its middle position. In the position shown it has been moved to the right far enough to partly uncover the passage, or port, leading to the left end of the cylinder, and steam is being admitted for the out stroke. At the same time exhaust-steam is discharging through the right-hand port to the hollow of the valve and thence through the central exhaust port to the open air. When the piston reaches the limit of its stroke to the right, the slide-valve will have moved to the left a sufficient distance to shut off the steam from the left end and admit it to the right end of the cylinder, and the hollow of the valve will be in the correct position to allow the steam from the left end to escape through the exhaust. The motion of the piston is

transmitted to the crank by means of the piston-rod, cross-head, and a connecting-rod, and the heavy fly-wheel keeps up the motion until the force of the steam can be applied on the return stroke.

The cross-head, where the piston-rod and connecting-rod are joined together, in this case slides back and

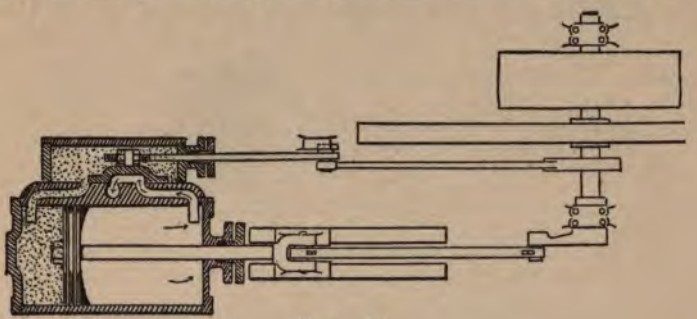

FIG. 39

forth over well-lubricated guides usually cast integral with the engine frame. Fig. 39 shows a top view of a cross-head and guides exactly like those shown in Fig. 38.

It will be seen that the cross-head is forked to receive the end of the connecting-rod and that there are two "slippers" between the cross-head pin and the guides on either side of the connecting-rod. The guides are double so as to allow the connecting-rod to drop between them on the return stroke.

A cross-head and guides of this description can only be used on an engine that does not reverse, and which turns "over" and not "under"—in which case the pressure on the guides will always be downward.

Side motion is prevented by means of lips on the cross-head which work on the inner vertical edges of the guides. In this case, motion is given to the slide-valve by means of an eccentric, rocker-arm, and valve-rod. The eccentric is shown in Fig. 38 by dotted lines only. Its construction will be better understood after an examination of Fig. 40. It consists of a circular

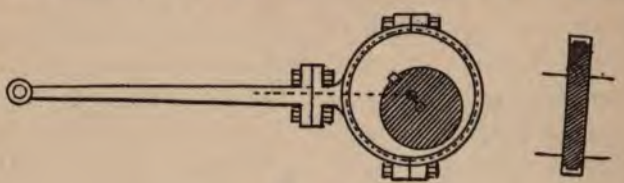

FIG. 40

disk, with its centre, a little to one side of that of the shaft to which it is keyed, connected to a rod by means of adjustable "straps" which fit over a projection on the edge of the disk—as shown at the right.

As the shaft revolves the eccentric disk is carried around with it and gives exactly the same motion to the rod as would be given by a short crank where the "throw" is equal to the distance between the centre of the shaft and the centre of the eccentric.

An eccentric may be regarded as a greatly enlarged crank-pin, and it is used when it is desired to give a crank motion at some other point than at the end of a shaft.

In Fig. 38 the rocker-arm gives a motion to the valve-rod exactly opposite to that of the eccentric-rod, but the proper motion is easily obtained by simply keying

the eccentric to the shaft in an opposite position from what would be required for direct action.

THE SLIDE-VALVE. Now, we come to a study of the most vital part of the engine—the slide-valve. In order to understand its operation the top view of the steam and exhaust parts, shown at *A*, Fig. 38, should be noted in connection with the sectional view of the same openings immediately below.

The ports are made of this shape so that a slight motion of the valve will give a comparatively large opening. The face of the valve as well as the surface on which it slides must, of course, be a perfect plane, so as to insure a steam-tight joint. Fig. 41 shows a slide-valve in its middle position. It will be noted that all the ports are covered, and that the outer edges of the valve lap over both steam ports a distance about equal to the width of the ports. This projection of the edge over the steam port, marked *L* in Fig. 41, is called the "lap" of the valve.

FIG. 41

Lap is necessary in order to have the valve open and close the steam-ports at the right time. Sometimes there is a slight lap of the inner edges of the valve on very quick running engines, but none is shown on Fig. 41. In order to understand the exact motion of the valve, we need to consider the motion that is given by the use of a crank. When a crank is near its

highest and lowest positions, it will push or pull a rod much faster than when it is in a position nearly in line with the rod. An eccentric acts in exactly the same way, and there will be two points in every revolution of the shaft where the valve will move quite rapidly, and two points where it will move very slowly. This is taken advantage of by designing the valve so that it will open and close quickly, and will remain open or closed long enough to properly distribute the steam.

It is of the greatest importance to have the eccentric keyed to the shaft at exactly the right angle with reference to the position of the crank of the engine. The two would be at right angles to each other except for the lap and "lead" of the valve which make it necessary to have the eccentric crank slightly in advance of a right angle with the main crank. "Lead" is the opening which the motion of the valve produces before the piston begins to move in the direction of the motion of the valve. In Fig. 38, let us suppose that the piston has moved as far as it can to the right. The crank will then be in a horizontal position—to the right—and the connecting-rod will also be in a horizontal position ready for the back stroke. If the engine were at rest in this position, no amount of steam pressure on the piston would have any tendency to turn the crank, but the heavy fly-wheel keeps up the motion, caused by the previous stroke, and carries the crank past the horizontal position where the steam pressure can become effective in turning it. Whenever the crank of a horizontal engine is in a horizontal position, it is said to be on a "dead centre." This occurs twice

in every revolution, but the inertia of the fly-wheel prevents the engine from stopping at these points.

Now, to return to the valve, it must have moved from the position shown in Fig. 38 so as to be slightly open and ready to admit steam to the right end of the cylinder and in position to allow the steam to exhaust, from the left end of the cylinder. It will be in the opposite position from that shown in Fig. 38, except that it will not be open quite so wide as there shown. Fortunately it is possible, by means of an eccentric, properly placed, to give the valve a quick motion when the main crank is nearing the dead centres and thus to admit and release the steam at the right time.

As the piston moves toward the left, with the full force of the steam behind it, the valve will move in the same direction for a time, thus holding the port open. But it would be a great waste of steam to keep the port open during the full length of the stroke as it would not allow expansive use of the steam. The port should be closed and the steam "cut off" before the piston reaches the end of the stroke. The lap of the valve allows this to be done, as shown in Fig. 41, where the right-hand end of the valve may be supposed to have shut off the steam from that end of the cylinder without yet having opened the exhaust-port. Referring again to Fig. 41, and supposing the valve to be still moving toward the right—opposite to the motion of the piston—there will immediately be opened up a passage toward the exhaust-pipe and very soon the lap at the left end of the valve will have uncovered the left port and steam will be admitted to

the left end of the cylinder. These changes in the position of the valve will be made quickly while the piston is making the last small fraction of its stroke toward the left and everything will be ready for the stroke toward the right, as shown in Fig. 38.

There is another reason why the valve should be opened slightly before the beginning of every stroke—or, rather, before the end of the previous stroke. The piston-rod, cross-head, and connecting-rod always move in the same direction as the piston, and must be brought to rest and started in the opposite direction twice in every revolution of the engine. By admitting steam a moment before the end of the stroke a "cushion" is produced which aids in bringing these moving parts to rest and raises the pressure for the beginning of the next stroke.

It is truly remarkable how such a simple piece of mechanism as the slide-valve can be made to accomplish so much as it does in admitting, cutting off, cushioning, and exhausting the steam from both ends of a steam-cylinder.

It is a trained engineer's job, however, to design a valve and its "gear" so as to produce all these results, and to set the eccentric and adjust the length of the valve rod so that the valve will serve both ends of the cylinder equally well.

In order that the motion of the slide-valve may be more thoroughly studied, it is suggested that the reader make tracings from Fig. 41 and experiment by moving the valve back and forth over the ports in the manner described above. The first tracing should

be made on a piece of paper about 4 inches square, including everything below the face of the valve, and only the dotted lines above. The second tracing should be of the valve only, on a narrow strip that will pass through slits cut in the first tracing along the short vertical lines under *A* and *B*.

Though the slide-valve is a wonderfully useful appliance, there are objections to its use on large engines. One of the drawbacks is the great amount of friction that has to be overcome in moving it back and forth over the ports with the heavy steam pressure on its back. Another objection is that steam cannot be cut off by it early enough in the stroke to get the best results in the way of using steam expansively.

Modifications have been invented, however, which, in a measure, overcome both of these objections without greatly changing the form of the valve. These will be explained farther on.

Fig. 39 shows a "plan," or top view, of an engine like that shown in "elevation" in Fig. 38, except that here the steam-chest is on the side of the cylinder instead of on top. This is, really, a more common and simple arrangement than that shown in Fig. 38, but it is not so easy, in this form, to study the relative motions of the crank and the valve-gearing.

By placing the steam-chest and slide-valve on one side of the cylinder, the rocker-arm is dispensed with and the valve rod and eccentric-rod are placed in line with each other, with only a joint and slide between. The relative positions of the crank, eccentric, fly-wheel, driving pulley, and bearings are plainly shown in

Fig. 39. Fig. 42 shows a simple guide for giving parallel motion to the connection between an eccentric-rod and a valve rod.

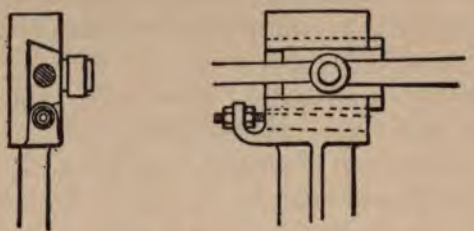

FIG. 42

Fig. 43 shows a balanced slide-valve. In the top of the valve there is a ring of packing which works against a finished surface on the under side of the steam-chest cover. This prevents the steam pressure from acting on the back of the valve and makes it easy to move back and forth.

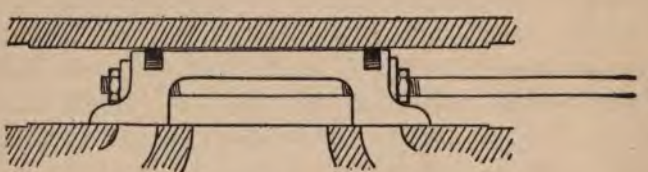

FIG. 43

Sometimes a slide-valve is made in the form of a piston working in a small cylinder with grooves and openings corresponding to the ports of an ordinary valve and valve-seat. In such a case spring packing-

rings similar to those used on the piston of the engine are used to make steam-tight joints. Such a valve is rather complicated and difficult to manufacture.

It has been stated that a plain slide-valve cannot be made to cut off steam much earlier than three-quarter stroke, and that this is too late a cut-off for the most economical use of steam. Fig. 44 shows a device that is used to produce an earlier cut-off. There are two separate valves, one working on the back of the other, each operated by a separate eccentric. The main valve

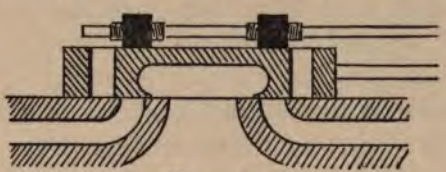

FIG. 44

operates like an ordinary slide-valve, except that it has a small lap and openings through the valve for controlling the passage of steam into the cylinder—instead of a mere edge. The upper or auxiliary valve, which slides back and forth on the back of the main valve consists of a pair of blocks, mounted on a single valve-stem. The eccentric which operates the auxiliary valve is set so that it moves one of the blocks over the opening in the main valve when it is desired to cut off the steam—instead of depending on the lap of the main valve covering the steam-port on the return movement. By the use of such a valve, steam can be cut off at one-third stroke, or earlier, without interfering with the exhaust.

The blocks are usually mounted on a rod with a right-hand screw-thread for one block and a left-hand thread for the other. By taking care to have the blocks in the same relative position with regard to the openings in the main valve, a turn of the rod in one direction will bring the blocks nearer together and a turn in the other direction will move them farther apart. In this way they can be adjusted as desired. Of course the surfaces must be accurately finished and some means be used to keep the auxiliary valve in its place. In a horizontal engine with the steam-chest on top, the mere weight of the blocks combined with the back pressure, will keep the auxiliary valve in position.

The cross-head and guides, shown in Fig. 38 and Fig. 45, are of the simplest form, for the engine is not

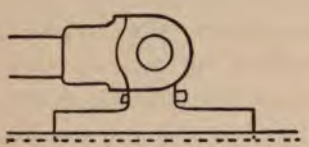

FIG. 45

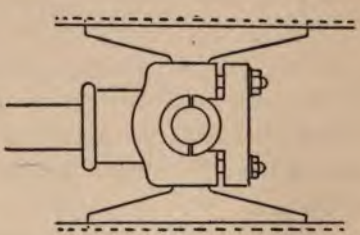

FIG. 46

reversible and turns over to the right. This causes a downward pressure at the cross-head which is taken care of by means of slides working in V-shaped guides on the under side only.

Reversible engines require cross-heads similar to that shown in Fig. 46, with bearings at the top as well

as at the bottom. The reason for this will be clear after a glance at Fig. 47.

The upper diagram shows how the force exerted on the cross-head, through the piston-rod, is met by the resistance of the connecting-rod and crank, which tends

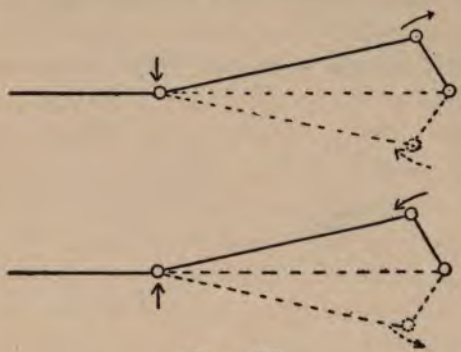

FIG. 47

to push the cross-head down. When the crank is below and the piston-rod is pulling instead of pushing on the cross-head the pressure will still be downward.

The lower diagram shows what would occur were this engine reversed and made to turn toward the left. The tendency would then be to raise the cross-head both when the piston-rod is pushing and when it is pulling.

A cross-head like that shown in Fig. 46 with adjustable guides, both above and below, is well calculated for use on a reversible engine, or on one that turns only toward the left.

THE CRANK. Fig. 48 shows two views of an unbalanced engine crank like that shown in Fig. 38.

It has been found, in practice, that the hub of such a crank should generally be twice the diameter of the shaft that it is to turn. The same rule applies to the smaller end as compared with the diameter of the crank-pin.

The crank should always be keyed very securely to

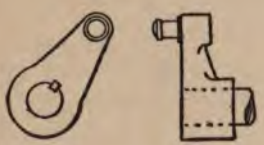

FIG. 48

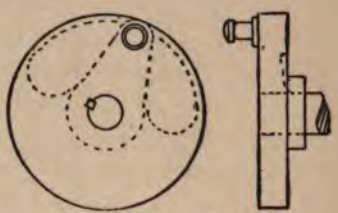

FIG. 49

the shaft, for the whole power of the engine is exerted at this point, and tends to make the crank slip around the shaft. The crank-pin has an enlarged end to prevent the connecting-rod from coming off. The adjustment for wear is always made on the connecting-rod. When an engine works rapidly there is a tendency for the crank and connecting-rod to swing away from the centre of the shaft, due to centrifugal force. This tendency is counteracted by means of a counterbalance placed opposite the crank. In such cases it is a common practice to use a disk weighted on the side opposite the crank-pin, as shown in Fig. 49. Here the disk has a plane front and is reinforced on the back, as indicated by the dotted lines.

Counter-weights are always prominent features of locomotive driving-wheels, where the movement is rapid and the connecting-rods and parallel-rods are heavy.

The Double Crank. Whenever it is necessary to have a crank midway on a shaft, instead of at the end, a form like that shown in Fig. 50 is used—or rather, like one-half of what is shown in Fig. 50, for here two double cranks are shown opposite to each other.

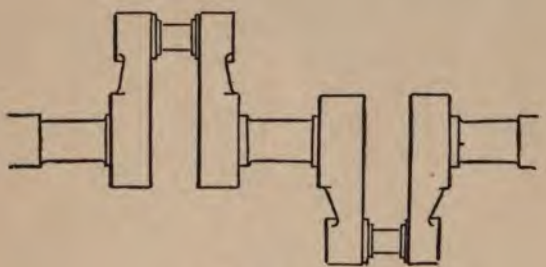

Fig. 50

Such cranks are much used on marine engines. It will be seen that each one of these cranks is made up of two like that shown in Fig. 48—placed one opposite the other and having a single crank-pin.

Small cranks of this description are often shaped out of the same piece of metal that the shaft is made from —in other words, they are made integral with the shaft.

Crank-shafts for automobiles, where there are sometimes as many as eight cylinders, are usually made from steel drop forgings of appropriate shape. The

making of a crank-shaft and its necessary "journals" involves a large amount of accurate machine work.

Connecting-Rods. Not only is it necessary to keep all the moving parts of an engine well lubricated, but there must be provision for accurate adjustment and for taking up wear at all important connections. This is particularly true of the connecting-rod bearings by means of which the force of the engine is transmitted from the piston-rod to the crank-pin. Not only is there a great deal of movement at these bearings, but the parts must be strong enough to withstand the full force of the engine.

Fig. 51 shows the common form of a connecting-rod

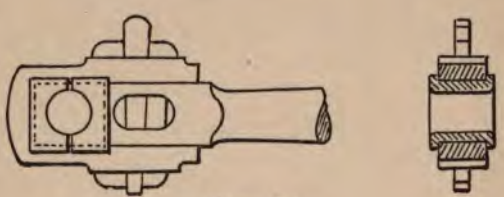

Fig. 51

end for use on a crank like that shown in Figs. 38 and 48. The rod here terminates in a square flat end against which rests a bushing made of composition metal in two parts which grasp the crank-pin and are held in place by means of a heavy "strap" of steel which draws the two parts of the bushing together and secures them to the connecting-rod. The strap is fastened to the connecting-rod by means of a wedge-shaped pin and two "cotters" which pass through the mortises

in the connecting-rod and strap. The cotters are put in first, and then the pin is inserted. This holds all parts firmly together.

A little study of the two views shown in Fig. 51 will make the construction clear. It will be noted that the two parts of the bushing do not touch each other. Whenever wear occurs a slight tap on the pin will draw the strap to the right and bring the left-hand bushing snug against the crank-pin. Sometimes the cotter-pin has a projection which engages with a screw-thread, by means of which it can be moved more accurately than by a stroke of a hammer. The oval opening through the rod near the bushing is only for the purpose of lightening the rod.

Fig. 52 shows three other forms of connecting-rod

FIG. 52

ends. The middle one is much used on double cranks, where end adjustment is necessary. It consists of a heavy moulded bushing in two parts held together, and to the connecting-rod, by means of heavy bolts which also pass through a steel plate at the outer end. Here the connecting-rod proper ends in a T with holes for the bolts.

At the left and right, Fig. 52, are shown two simple

forms of connecting-rod ends that are used on valve connections, and other places, where there is not much power transmitted and comparatively little wear. In both cases bushings are inserted in openings cut out of the solid rod, and adjustments are made by means of bolts and nuts. In the one shown at the left, a short wedge is drawn against the bushing by means of a screw. In the one at the right the adjustment is made by means of a "split" in one side of the opening in the rod.

Fig. 53 shows a forked connecting-rod such as is

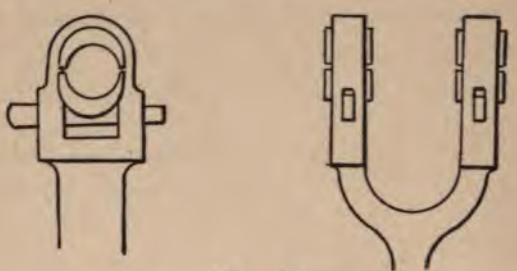

FIG. 53

often used on engine and valve connections—especially in marine work. The bushings and adjustments are doubled, in this case, but are not necessarily of the exact form shown in Fig. 53.

It must be clear that all pieces of mechanism of the kind shown in Figs. 51, 52, and 53 must be very accurately fitted in order to prevent the different parts from moving out of place under the heavy strains that they are subjected to.

PILLOW-BLOCKS. The main bearings of an engine shaft are very important. They should be constructed with reference not only to the power which is to be transmitted, but also to the weight of the fly-wheel and other heavy parts which they must carry. The bearing next the crank is generally firmly attached to the engine-frame—or else made a part of it. This bearing must withstand the heavy push and pull of the engine and is generally made on a slant so that the heavy thrust and pull of the connecting-rod will be opposed by the body of the bearing and not by the joint between the bearing and cap.

Fig. 54 shows a common form of bearing for the outer end of an engine shaft. It is called a pillow-block, and it is made up of two parts each of which carries a bushing next the shaft, as shown in the half section. Sometimes the bushing is of solid composition, inserted as shown, and sometimes it is a mere film of Babbitt metal cast around the shaft while the latter is held in exact position by temporary supports. A little space is always left between the main bearing and the cap so that any wear may be taken up by screwing down the bolts that hold the cap in place. Pillow-blocks and engine-frames are usually placed on heavy concrete foundations, and held in place by means of long rods imbedded in the concrete.

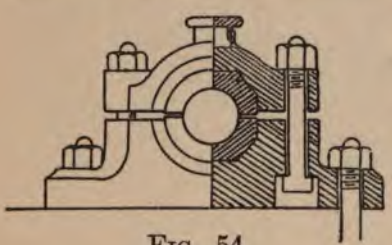

FIG. 54

Fig. 55 shows a section of a "thrust-bearing," such as is used to support shafts of screw-propellers. Solid collars are turned on the shaft and the thrust is divided between them.

FIG. 55

The thrust-blocks on ocean liners are often very massive affairs—8 or 10 feet long, with passages both in the main bearing and in the cap through which water is constantly pumped to keep the bearing cool.

THE LINK MOTION. To return again to the subject of valve-gearing, let us suppose that it is desirable to reverse the motion of the engine, as must often be done in the case of a locomotive or a marine engine. This can be done by reversing the motion of the slide-valve,

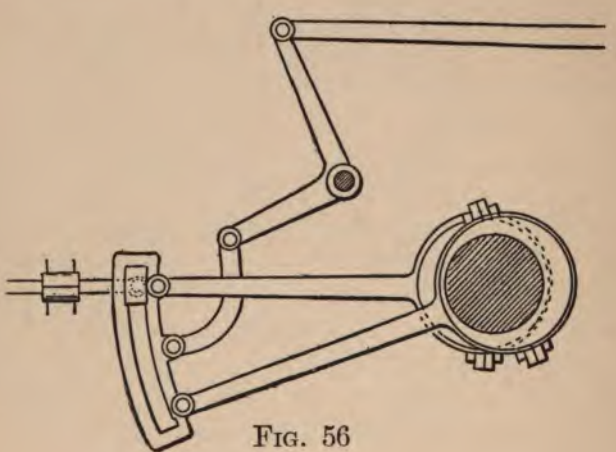

FIG. 56

and the device in most common use for this purpose is the "link motion," shown in Fig. 56. It consists of a curved link of steel having an eccentric connected with each end and carrying a block attached to the end of the valve rod. One eccentric is set for running forward and the other for running backward. The link is suspended on a system of levers by means of which the engineer can raise or lower the link so as to bring either eccentric-rod in line with the valve rod—according as he may desire to have the engine run forward or backward. In the position shown in Fig. 56 the same motion is given to the valve rod as though there were but one eccentric, which we will suppose is properly set for running the engine forward.

The other end of the link will be moved back and forth without materially affecting the motion of the valve. Now suppose the engineer desires to reverse his engine. He merely has to shift his levers so that the

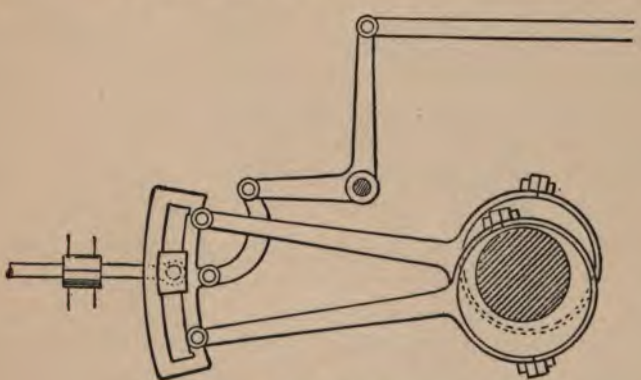

FIG. 57

link is raised and the lower eccentric-rod brought in line with the valve rod. When this is done the upper eccentric is put out of use and the lower one gives the correct motion to the valve for running in the opposite direction. The block attached to the valve rod is fitted loosely so that it will slide easily in the link. There is a slight up-and-down motion to the link due to its method of suspension, but not enough to materially affect the motion of the valve. Fig. 57 shows a link motion in neutral position. While the link is held in this position the engine can neither go forward nor backward. There are, however, points between the neutral position and either extreme position where the link may be held, and a motion given to the valve which will produce an earlier cut-off than the extreme position. This "hooking-up" process is often employed to save steam on locomotives when full power is not required. Fig. 58 shows a shifting-lever for a link motion such as is used on locomotives. Other forms of reversing-gears will be explained under the subject of the locomotive.

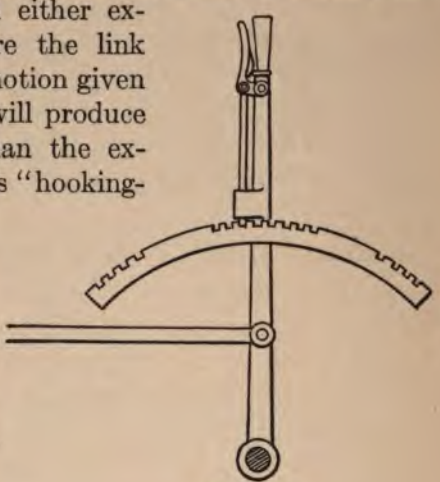

FIG. 58

PISTONS. There is no part of an engine more im-

portant than the piston. It receives the direct pressure of the steam and transmits it to the other working parts. It is very important to have it work steam-tight—or as nearly so as possible. For this purpose packing-rings, of slightly larger diameter than the piston and cut diagonally across in one or more places, are sprung into grooves in the edge of the piston as shown in Fig. 59. These rings spring outward and make the

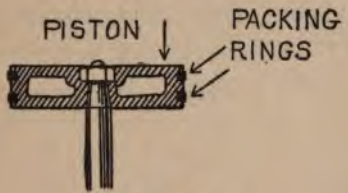

FIG. 59

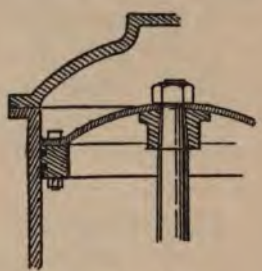

FIG. 60

joint between the piston and cylinder very nearly, if not quite, steam-tight. Two or more rings are used so that any small amount of steam that may leak past one may be stopped by another. Various forms of packing-rings are used, some of which are more effective than others.

Fig. 59 shows an ordinary cast-iron piston, such as is used on small engines. The end of the piston-rod is tapered and drawn into a hole of corresponding taper, by means of a nut and screw-thread. The nut generally rests in a recess so that the piston may move to the end of the cylinder.

Fig. 60 shows a form of piston used in large engines. It is made up of a solid ring, which carries the packing, and a dome-shaped plate of steel attached to the piston-rod. Here the nut cannot well be concealed, so a recess is made in the cylinder cover to receive it. A piston of this description is much lighter, for a given diameter, than the kind shown in Fig. 59.

Stuffing-Boxes. Fig. 61 shows a common "stuffing-box" for preventing leakage around a piston-rod. It consists of two parts. An enlarged opening at the point where the piston-rod passes through the cylinder-head and a flanged "gland" which fits loosely over the piston-rod and into the opening. The gland is forced into the opening by means of stud-bolts and nuts, and well-oiled cotton packing is thereby squeezed into place so as to make the joint around the rod steam-tight.

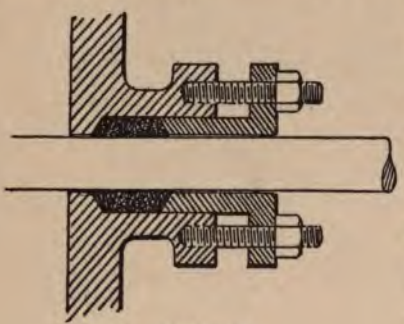

Fig. 61

This method of packing piston-rods has been practised since the time of Watt. Engines that use high-pressure superheated steam are generally packed with metal rings similar to those used on pistons.

Vertical Engines. Fig. 62 shows one of the simplest forms of the vertical engine. Direct-acting vertical engines take up little room, and, for many pur-

poses such as marine work, they are to be preferred to any other type. The one shown in Fig. 62 has a link motion and can be run either right or left handed. There is not much room for a fly-wheel, in this case, on account of the shaft being so near the bottom; but in marine work fly-wheels are generally dispensed with entirely. Massive cast-iron frames are often used for vertical engines; the cylinders of marine engines are usually supported on well-braced heavy steel rods.

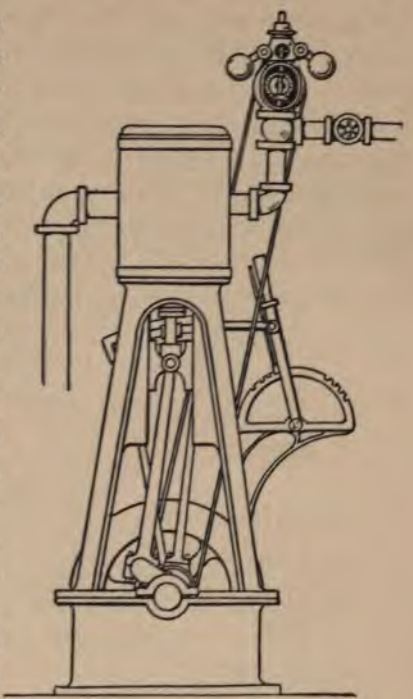

FIG. 62

GOVERNORS. In Fig. 62 an important adjunct to the steam-engine is shown that has not yet been described, namely, the "governor." Wherever the load on an engine varies greatly, as it does in mill and factory work, governors are necessary to regulate the supply of steam, so as to keep the engine from slowing down when the load is heavy and to keep it from running wild when the load lightens. Fig. 63 shows the construction of a

common governor. There are two iron balls each of which is attached to a short lever pivoted to a revolving part. The upper end of each lever ends in a knob-like head which engages with a groove on a spool-shaped projection near the top of a light spindle. The balls and spindle are made to revolve by means of a set of small bevel gears, one of which is attached to a short horizontal shaft carrying a small pulley near the lower end of the spindle. On a prolongation of the vertical spindle, which does not revolve, are two conical valves controlling openings from the steam supply to the engine. The pulley on the horizontal shaft is connected with another pulley on the engine shaft by means of a belt. Motion is thus communicated to the balls. Whenever the engine slows down, because of excessive load, the balls, which have been raised as they revolved by the action of centrifugal force, drop a little. This raises the valve-stem and opens a wider passage for the steam and the engine "picks up" to carry the extra load. If the engine starts to run too fast, due to a light load, the balls fly out, the valve-stem is pushed down, and the steam passage is narrowed. By thus controlling the admission of the steam to the cylinder the speed of the engine is kept nearly uniform under varying loads—except in

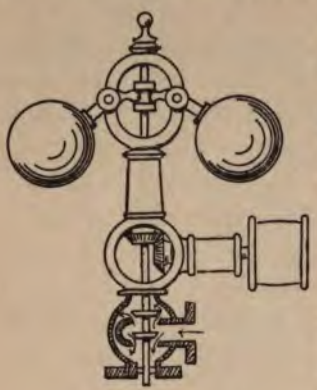

FIG. 63

cases where the load is too heavy for the engine to carry.

Corliss Engines. During the latter part of the last century a type of engine was developed by Mr. George H. Corliss, an American, which is much used for driving factories, and other large plants, where variable loads are carried, and where economy of fuel is an important consideration.

Corliss engines are now built by many different manufacturers and vary somewhat in detail, but the main features are essentially the same in all.

The Corliss valve is a distinctive feature, which calls for special explanation. Its construction and the method of its control are different from anything yet described. Fig. 64 shows cross-sections of valves of the Corliss type. The one at the right is an admission-valve, and the one at the left an exhaust-valve. Fig. 65 shows a general view of an admission-valve in its "housing" at one end of the steam-chest, which is usually at the top and of the same length as the cylinder.

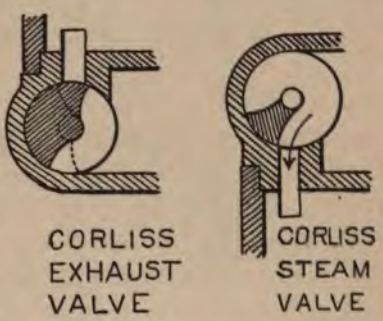

Fig. 64

The valves are located as close to the ends of the cylinder as possible and are of about the same length as the diameter of the piston. They rotate about axes at right angles to the axis of the cylinder and each valve

opens and closes a single port. The admission-valve, as will be seen by Figs. 64 and 65, may be described as a bar rotating about one of its edges, while the other edge opens and closes the steam passage. The working edge of the valve is segmental in shape and fits very

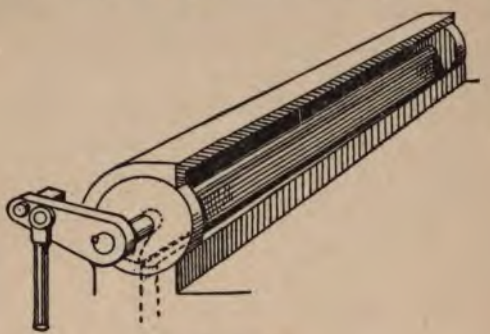

FIG. 65

accurately a housing, of corresponding shape, which connects with the cylinder by means of a long narrow port. One side of the housing connects directly with the steam-chest. The bar-shaped valve has cylindrical ends which fit into corresponding shapes at the ends of the housing, and the whole is rotated by means of a short lever-arm on the outside.

The exhaust-valves are on the side opposite the admission-valves—usually at the bottom of the cylinder—and, though different in cross-section, operate in the same way.

The admission-valve shown in the figures is open, and it can easily be seen that a slight rotation would completely close the port. The exhaust-valve shown at

the left, Fig. 64, is closed. If turned slightly toward the left, as indicated by the dotted lines, the port would be opened.

THE CORLISS VALVE-GEAR. Fig. 66 shows a Corliss

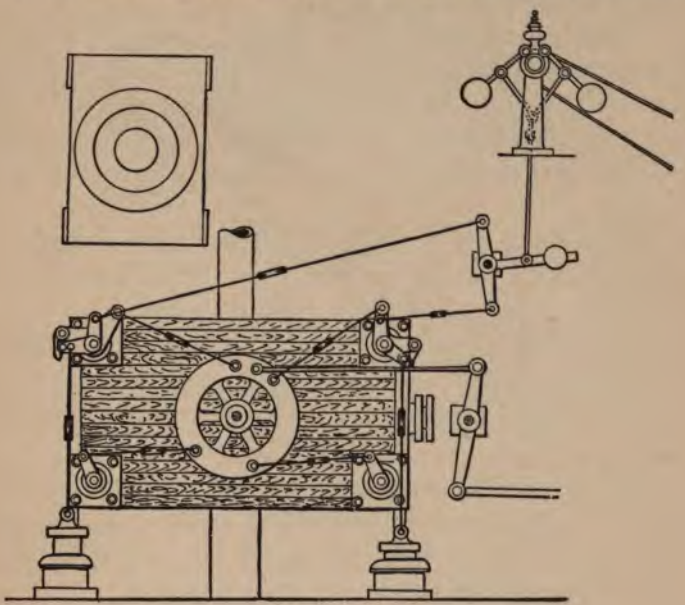

FIG. 66

cylinder, fitted with valves, and the general arrangement of the controlling mechanism.

The outside of the cylinder takes the form of an oblong box of nearly square cross-section, because of the long and wide steam-chest, at the top, and a corresponding exhaust passage, at the bottom of the cylinder. Steam-chest, valves, steam passages, and cylinder are

usually enclosed by wooden lagging which conceals the divisions between the various parts. The cylinders are usually completely steam-jacketed. This, together with the wooden lagging, prevents radiation and keeps the working parts always hot.

Motion is given to the valves by means of a single eccentric working a rocker-arm, which, in turn, is connected with an oscillating disk, or wrist-plate, on one side of the cylinder. The oscillating disk is connected with each of the four valves by means of rods and lever-arms.

The action of the exhuast-valves, at the bottom, is very simple; they are made to rotate back and forth over the ports by direct connection, as shown.

The action of the admission-valves is more complicated, but a little study of Figs. 65, 67, and 68 in connection with Fig. 66, will, we trust, make everything clear.

The admission-valves are not only moved by the eccentric and disk connections, but their release for the cut-off is controlled by the governor by means of a somewhat complicated piece of mechanism.

Figs. 67 and 68 show the usual mechanism attached to the admission-valve stems. There is first, a crank arm connected with the valve-stem which carries a cubical block on the inside and a vertical rod leading to a "dash-pot" which will be described later. Fig. 65 shows this part of the mechanism with other parts removed. Fig. 67 shows this crank arm in dotted lines, only, so as not to conceal the parts behind it. Fig. 68 shows the crank arm in the position it takes when

the valve is closed. This crank arm is, of course, firmly keyed to the valve-stem. On the valve-stem are two other crank arms, fitting loosely. One of these

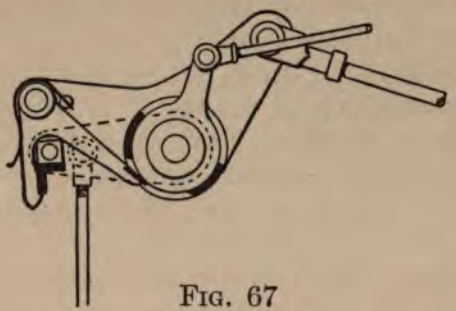

FIG. 67

is in the form of a "bell-crank" with two arms at right angles, one of which is connected with the oscillating disk by means of a rod. The other arm of this bell-crank carries a two-armed hook which has a slight

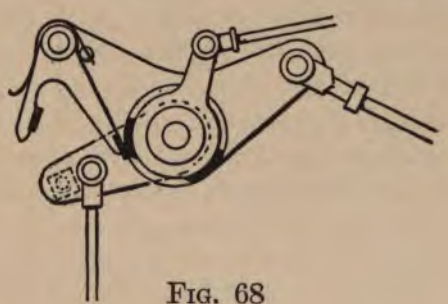

FIG. 68

motion, about a pin, which is controlled by a spring. The hooked end, of the last mentioned piece, carries a small square-edged piece of steel—black in the figure—

which hooks over the block on the valve crank. The other end of the hooking device runs back at an angle toward the valve-stem where it engages with cams on the hub of still another crank arm which is connected by a rod to a three-armed lever operated by the governor. The largest bell-crank, carrying the hook, oscillates regularly with the motion of the wrist-plate, and carries the hook up and down with it. Fig. 67 shows these parts in one position and Fig. 68 in another. The crank arm carrying the cams—shown in black—moves only slightly back and forth under the control of the governor; as it does so the positions of the cams are slightly changed. Every time the hook reaches its lowest position, it engages the block on the valve lever-arm and raises it. This opens the valve and admits steam to that end of the cylinder. As the hook rises, carrying the valve lever-arm with it, the arm connected with the hook finally engages with the cam. This throws the hook out, the valve crank arm is then quickly drawn down by the action of the "dash-pot," and the steam is shut off.

It can readily be seen that the cut-off is controlled by the position of the cam; and the position of the cam is varied by the governor according as the engine needs more or less steam to carry its load.

If the engine slows down at all, on account of a heavy load, the governor-balls fall a little; this lowers the weighted arm of the three-arm lever, Fig. 66, while the other two arms, operating through the rods, move the cam levers to positions that allow the hooks to rise a little higher before being released. This simply means

that the admission-valve is held open a little longer and more steam is admitted to carry the load. In other words, the cut-off occurs later in the stroke and the engine produces more power, but uses more steam.

In case the load is suddenly lightened and the engine begins to run too fast, the governor-balls fly out; the weighted arm is raised; the cams are moved into a position which will release the hook earlier in the stroke; less steam is admitted and the engine slows down. It will be seen that both of the admission-valves are controlled by the governor at the same time. This method of controlling the speed of the engine, under varying loads, by changing the point of cut-off, is an improvement on the method by which the common governor merely throttles the steam in the steam supply pipe. It is much more sensitive and efficient.

Dash-Pots. Whenever the admission-valves are released, it is desirable to have them close quickly, and then come to rest without shock. Both of these objects are attained by means of a dash-pot of peculiar construction. Fig. 66 shows a dash-pot, on the floor level, at each end of the cylinder. Fig. 69 shows the construction of a common form of this device. It consists of a short, double cylinder, resting on a solid foundation, and a piston of corresponding shape which has a vertical movement of a few inches only. The fixed cylinder has a raised central portion which acts like a piston in a corresponding part of the movable piece. These parts are so carefully fitted that a few drops of oil, on the rubbing surfaces, make the parts work practically air-tight. A curved cover keeps dust

and dirt from getting inside. Attached to the movable part is a vertical rod of adjustable length, shown in Fig. 66, connecting it with the lever-arm of the valve rod above. As the hook engages with the block on the valve lever, the movable part of the dash-pot is

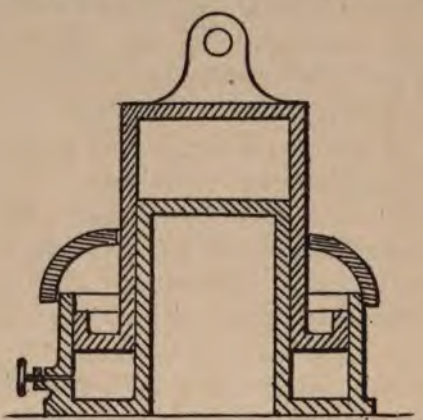

FIG. 69

raised, and a partial vacuum is created in the space below the piston, and in the space at the top as well. This brings a heavy pull on the rod, caused by atmospheric pressure; and the moment the hook is released the valve is given a quick closing movement.

Near the bottom of the fixed part there is a very small opening controlled by a thumb-screw by means of which a small amount of air is drawn into the partial vacuum in the lower compartment.

When the movable part is suddenly drawn back this air forms a cushion which prevents the two metal parts

from striking each other, and brings the moving part to rest, without shock.

Sometimes two Corliss cylinders are placed "tandem"; that is to say, what is practically a single piston-rod passes through both cylinders and transmits the thrust and pull of the two pistons.

At the upper left-hand corner of Fig. 66, is shown an end view of a Corliss cylinder and steam-chest, without the usual attachments.

Compound Engines. Something has already been said about the advantage to be gained by using steam expansively. Watt understood this and his later engines were designed to cut off the steam supply some time before the end of the stroke. We have seen that common slide-valve engines can be adjusted to cut off steam at three-quarters stroke, and that the Meyer valve allows of a much earlier cut-off. But there is a practical limit to the expansive use of steam in a single cylinder.

When steam is made to do work by its expansive force, like driving a piston, it is cooled as a consequence. The cylinder walls are cooled at the same time. The supply of steam for the next stroke must, then, lose a certain amount of its heat on entering the partially cooled cylinder, before it can do any work; and this loss of heat is an absolute waste. The steam-engine can only produce power as it converts the heat of the steam into moving force, and all the heat that escapes with the exhaust together with that employed in reheating the cylinder is, of course, absolutely wasted.

A knowledge of these facts has led engine designers

to seek some way of utilizing a greater proportion of the heat of the steam. A long step in advance was taken when it occurred to some one to use the steam that was exhausted from one high-pressure cylinder in a second cylinder coupled up with the same shaft as the first.

This arrangement is called a compound engine and its principle may be studied with the aid of Fig. 70.

At the left, is shown a high-pressure cylinder which takes steam directly from the boiler and uses it expansively through, say, the last one-third of its stroke. When the piston has completed its stroke, this steam is exhausted into a receiver shown between the two cylinders. This receiver may be merely an enlarged steam-chest for a second cylinder—larger than the first—which now takes the partially expanded steam, and uses it expansively through an entire stroke. Here, each cylinder remains at practically the same temperature as the steam which enters it, and the first will be much hotter than the second. The second cylinder is made larger than the first for the reason that the steam increases in volume as it moves on and the second cylinder must be properly proportioned to use all the steam that comes from the first cylinder. The cylinders of a compound engine may be so proportioned as to divide equally the energy of the steam between the two. It is the usual practice to use piston-rods and connecting-rods of the same size for both cylinders.

FIG. 70

Connection may be made with two cranks, either opposite or at an angle of ninety degrees with each other.

There will still be a good deal of heat left in the steam after it has escaped from the second cylinder, and it may be used again in a third, and still larger cylinder. Where steam is used in three cylinders the engine is called a triple expansion-engine. Sometimes, even a fourth cylinder is added, and such an engine is called a quadruple expansion-engine.

It has been found in practice that it does not pay to use more than four cylinders; and seldom does it pay to use more than three, for the extra weight of the parts consumes power and more than offsets the gain when too many cylinders are used. Sometimes four cylinders are used on triple expansion-engines. That is to say, instead of a third enormously large cylinder, two cylinders of equal size and but little larger than the second cylinder are used for the third expansion. A well-designed triple expansion-engine, exhausting into a condenser, will develop several times as much power as a single-cylinder engine exhausting into the open air.

CONDENSERS. The condenser was one of the most important features of Watt's engine; and Newcomen, before the time of Watt, as we have seen, depended entirely on the principle of the condenser for producing a condition which allowed the pressure of the atmosphere to become effective.

After the time of Watt, simple high-pressure engines were developed that did not need condensers to make them operate; but such engines are wasteful of steam

and fuel. The best engineers have always held to Watt's principle of utilizing a vacuum, and have recognized the condenser as a valuable auxiliary to the steam-engine.

Condensers are of two kinds. One, in which the condensing water and the condensed steam are mixed together, is called a jet condenser; the other, where the condensing water and condensed steam are separated, is called a surface condenser.

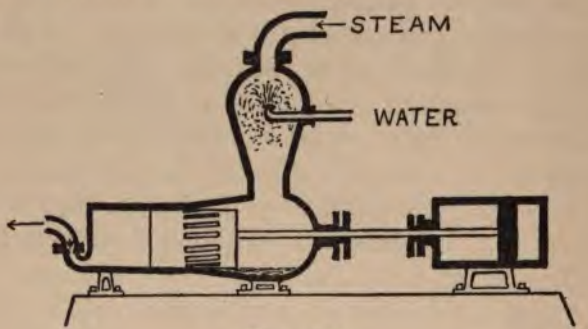

FIG. 71

In the jet condenser, see Fig. 71, the steam meets a jet of cold water as it comes from the exhaust of the engine.

The water from the condensed steam and that from the jet fall together to the bottom of the condenser where there is a pump that removes it, together with any air that may have entered with the jet—or otherwise. Sometimes this pump is operated directly by steam, as shown in Fig. 71, and sometimes it is operated by a lever connected with the cross-head of the engine—

or with one of the cross-heads in the case of a compound engine. It may occur to the reader that the power that is required to operate the air-pump, as it is called, must be subtracted from the total power of the engine before the effective power can be determined. Fortunately it takes but a small fraction of the power that is gained by the use of the condenser to operate the air-pump so there is a large gain by its use. Condensers are seldom used at the present day in connection with single-cylinder engines, for it has been found more economical to generate steam at moderately high pressure and to expand it through *two or more* cylinders, the last one of which is connected with a condenser.

Compound engines may exhaust into the open air—as they do in the case of the compound locomotive—but whenever it is possible to use condensers they are considered an almost necessary adjunct to the compound multiple expansion-engine.

In marine work, where there is always a good supply of water, condensers are nearly always used. Boats operating in fresh water, where the boiler supply can be drawn directly from the condenser, generally use the jet variety; but boats operating on salt water are obliged to use surface condensers, because the salt water used for cooling cannot be mixed with the fresh water from the condensed steam without injuring the boilers.

Fig. 72 shows the construction of a surface condenser. It consists of a closed vessel through which pass a great number of small copper tubes. Cold water is constantly being pumped through the tubes while the

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exhaust steam from the engine is discharged against the outside of them. The cold surfaces of the copper tubes immediately condense the steam, and the water that is thus formed in the bottom of the condenser is removed, together with any air that may have en-

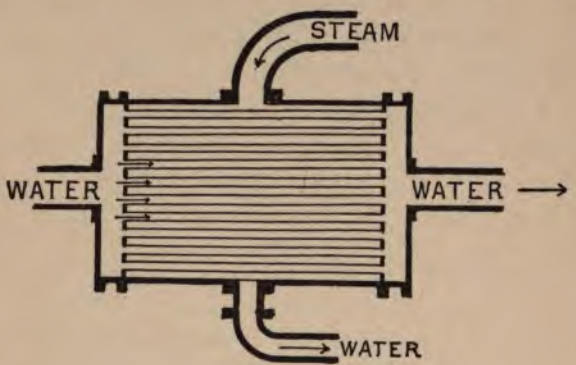

FIG. 72

tered, by means of a pump, as in the case of the jet condenser. The water of condensation is all returned to the boiler, and, inasmuch as it results from the condensation of all the steam that has been used to operate the engine, it supplies nearly all the feed water needed.

There is always some loss, however, from boilers blowing off and from leakage, so a small supply of fresh water has to be kept on board steamers for making up any loss.

In reciprocating engines, some oil always passes into the condenser with the exhaust steam; and it is generally necessary to pass the water of condensation

through a "separator" before pumping it back into the boiler.

A perfect vacuum is never produced by even the best condensers, but a very near approach to a vacuum is obtained in the best marine practice. From twelve to fourteen pounds, of additional effective pressure, is usually obtained by the use of modern condensers.

In locomotive practice it is found difficult to carry about the large amount of cold water needed for operating a condenser; so high-pressure steam—sometimes with expansion through two cylinders—is employed, exhausting directly into the open air.

CHAPTER V

THE LOCOMOTIVE

After Watt had succeeded in making a practical success of the steam-engine, attempts were made to apply it to the driving of various kinds of vehicles. M. Gugnot, a Frenchman, succeeded as early as 1769 in constructing a steam-truck for drawing artillery on military roads, but it did not prove to be of much practical use. Thirty-five years later an Englishman named Richard Trevithick built a locomotive that ran on rails. Soon afterward, he built a tramway in London on which he ran his steam-motors at the rate of about twelve miles per hour.

People were beginning to realize that the steam-engine could be applied to the driving of vehicles on rails that were level—or nearly so—but it was not until some time afterward that this method of propulsion was proven to be superior to horses, in practical operation.

About this time George Stephenson, in England, took hold of the problem in earnest. In 1823 he built the "Locomotion," which was quite an advance over all previous attempts to produce a self-propelling vehicle. But even this was soon discarded in favor of horses, for passenger traffic.

Soon after this Stephenson was appointed engineer of a tramway which was operated between Liverpool and Manchester, and he finally succeeded in persuad-

ing the directors to give the steam locomotive a trial. He built the "Rocket" which was the first locomotive to prove itself superior to horses, as a means of propulsion, on a railroad.

Fig. 73 shows the construction of this small but suc-

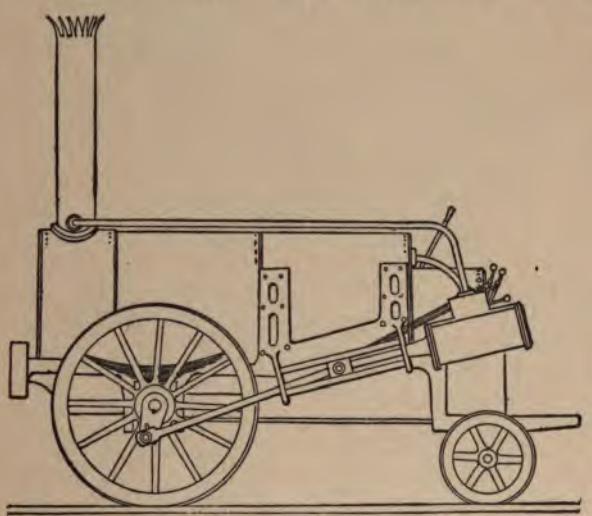

FIG. 73

cessful engine, the real forerunner of the modern locomotive.

It will be seen that the principal features of the modern locomotive were nearly all present in the Rocket. The first thing we notice is that the driving parts appear to be reversed, while the smoke-box, stack, and buffers seem to be in their right places. The cylinders are at the back end of the boiler, and the driving-wheels

are near the front—just the reverse of the arrangement to-day. This arrangement naturally suggested itself to the early builders, for it brought the main working parts near the "footboard," where the engineer and his helper were stationed. If the driving-gear were turned around, a wide flaring smoke-stack shown in place of the one in the figure and another pair of driving-wheels added, the general appearance would be much like the locomotives used in the United States in the time of Abraham Lincoln.

The Rocket had a boiler only 6 feet long, but there was a small internal fire-box at the back end connected by tubes with a smoke-box in front—like the arrangement to-day. The valve-gear was very crude and the engine was not reversible. There were springs between the frame and the driving-axles, and the exhaust-pipe was carried along the top of the boiler and connected with the smoke-stack.

The weight of the engine was four and a half tons—about one-fortieth of the weight of a modern freight locomotive.

The great number of improvements that have been made in the locomotive since the day of the Rocket have been gradually brought about, as suggestions have come one at a time to the minds of the builders, to meet the demands of service.

One of the first necessities was a means of reversing the engine, and this problem was solved by the adoption of the link motion already described. The Stephenson link motion shown in Fig. 56 was first used on one of Stephenson's locomotives, but it is said to

have been the invention of one of Stephenson's assistants named Howe.

This was a great improvement, for it not only enabled the engineer to run his engine backward, when necessary, but made it possible for him to vary the cut-off and save steam when less than the full power of the engine was required.

Without attempting to trace other improvements in the order of their adoption, let us now study the features of the modern locomotive. Fig. 74 shows a modern locomotive, such as is used for passenger traffic in the United States. The boiler is of the kind shown in Fig. 25, but the details and proportions are slightly different. The fire-box is large and placed behind the driving-wheels. There is a small steam-dome, for the safety-valve and whistle, as well as a larger one for the main steam supply. There is a four-wheeled truck at the front and a "pony truck" under the fire-box. There are springs between the frame and the axles connected with equalizing levers to be later described.

Piston valves, with inside admission, are operated by means of an improved form of the Walchaert valve-gear. Air-brakes are provided for all the drivers and the pony truck, and all devices are under the control of the engineer in the "cab."

The standard railroad gauge, 4 feet 8½ inches, was adopted at an early date so that cars could be interchanged between different roads. Tunnels and bridges were made to correspond and it was afterward found impractical to change, though it was found more and

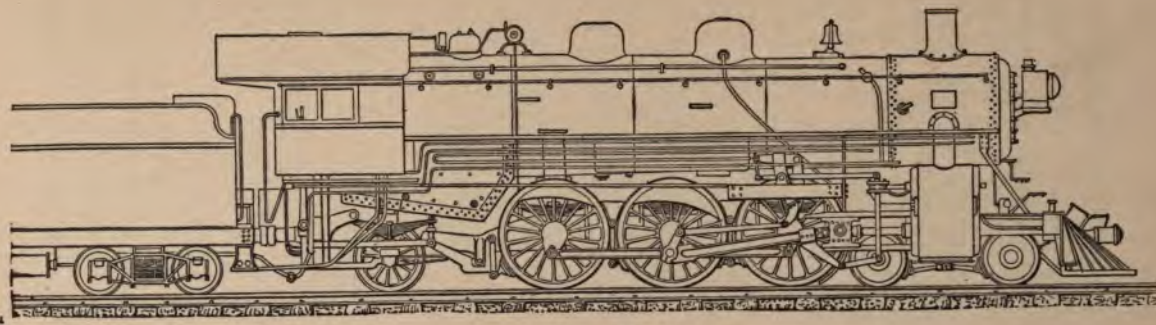

FIG. 74

MODERN PASSENGER LOCOMOTIVE—PACIFIC TYPE

(From a photograph furnished by the American Locomotive Company of New York)

Cylinders 25 inches in diameter, 26-inch stroke. Driving-wheels 6 feet and 3 inches in diameter. Fire-box 9 feet long and 5 feet 10 inches in width. Boiler 6 feet in diameter, designed to carry a steam pressure of 180 pounds to the square inch. Number of 5⅜-inch tubes, 30; 2-inch tubes, 210. Wheel-base: Driving, 13 feet 6 inches; engine 34 feet 7 inches; engine and tender 66 feet 3 inches. Weight of engine 264,000 pounds. Weight on driving-wheels 163,000 pounds. Maximum tractive power 33,200 pounds. Cylindrical slide-valves with inside admission. Kingan-Ripkin valve-gear.

The boiler of Stephenson's "Rocket" was about one and a half times the length of the cylinder, and less than the diameter of the driving-wheels, of this modern locomotive.

more difficult to adapt the proportions of locomotives of increasing weight to the same gauge as the four and a half ton Rocket. Fire-boxes were originally placed between the driving-wheels and frames, which limited their width to something less than four feet. This width was found to be entirely inadequate for large locomotives, burning bituminous coal; and the boilers had to be placed higher so that the fire-box could be placed entirely above the frame and either above or behind the driving-wheels.

Grates and Ash-Pans. Fig. 75 shows a modern

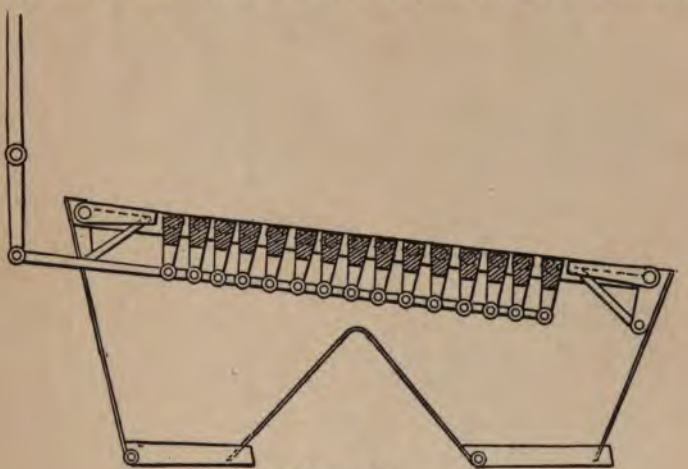

Fig. 75

locomotive grate and ash-pan. The grate-bars are hung on journals at each end and have short lever-arms that attach to a shaking device controlled from the cab. In front and behind the grate-bars there are

plates that can be dropped down whenever it is necessary to draw the fire. The ash-pan is humped up in the middle to make room for the pony-truck axle. Two hinged bottoms are arranged for dumping ashes and clinkers when necessary.

THE ARTIFICIAL DRAFT. When the locomotive is under way, a strong draft is produced by an exhaust-pipe, Fig. 76, which takes the exhaust steam from both cylinders and discharges it in the smoke-box directly under the short smoke-stack. Exhaust-pipes are generally provided with movable nozzles, with different sized openings, so that the blast may be regulated as needed. Modern smoke-stacks, steam-domes, and other accessories that are carried above the line of the top of the boiler are much smaller in proportion than on the earlier engines for the reason that there is much less room between the tops of the big boilers and the roofs of tunnels and bridges than formerly.

FIG. 76

THE FRAME AND SPRINGS. A very important part of a locomotive—though inconspicuous in the general view—is the frame.

The boiler, cylinders, and fixed points in the valve mechanism are all firmly attached to the frame, but the driving-wheels and other running gear are connected with it through the medium of springs as in carriages and automobiles. Fig. 77 shows the main portion of a locomotive frame, made of very heavy steel

bars. The single bar at the right is attached to the front end of the boiler by means of cross-braces and heavy castings at the base of the smoke-box. The cylinder casting is attached to the end of this bar. The other part of the frame carries a set of vertical jaws

FIG. 77

for each driving-axle, as shown, and is attached to the single bar by means of bolts and cotters. Each jaw has one vertical and one slanting leg, so that the driving-blocks may be adjusted laterally.

DRIVING-BLOCKS. Fig. 78 shows the details of a driving-block. It consists of a heavy casting with a bushing, to receive the driving-shaft journal, and an "oil-cellar" below the bushing. The weight of the boiler makes a bushing at the bottom unnecessary. The oil-cellar is removable and is kept full of oil and waste for lubricating the journal. There are grooves at the right and left which fit into the jaws of the frame, and recesses at the top for receiving the "fork" which passes on both sides of the frame and supports the spring as shown at A, Fig. 79.

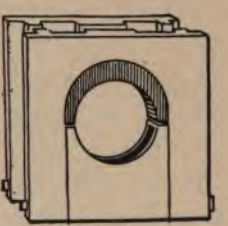

FIG. 78

A wedge, adjusted by means of a screw, is fitted between one side of the bearing-block and the sloping leg of the frame. Fig. 79 shows the bearing-blocks in position and the manner of attaching them to the springs. The springs for all the drivers are connected

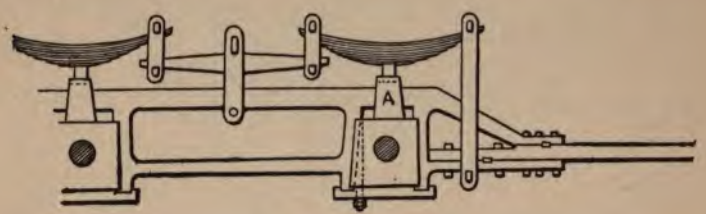

FIG. 79

together by means of equalizing bars and hangers, so that any wheel may pass over an obstruction without very much affecting the general balance of the locomotive. The wheels attached to any one axle may be raised an inch or two, so that the flanges no longer tend to keep them on the track, without danger of the locomotive being derailed so long as the other wheels are in proper position. The bearing-blocks are, of course, adjusted so as to move slightly up and down without any side play. Spanners are used to keep the frame legs from spreading. The pony-truck springs are connected by means of equalizing bars with the springs over the driving-axles. The back end of the boiler is fastened rigidly to the frame by means of cross-braces, and the general effect of all the supports between the locomotive and its running gear is similar

to the "three-point suspension" employed on automobiles. It allows of a considerable amount of flexibility, both vertically and horizontally.

TIRES. The driving-wheels of a locomotive are usually of cast iron, but a heavy flanged steel tire is used next to the rail. Fig. 80 shows a section of a locomotive tire.

It will be noted that the "tread" is slightly conical,

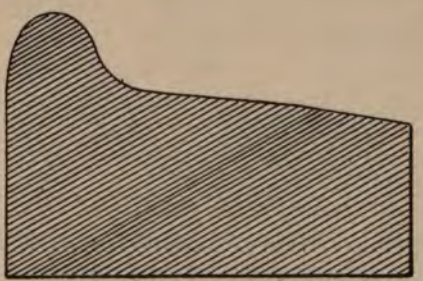

FIG. 80

and that the flange is only about an inch deep with a reversed curve between it and the "tread." It is a marvel to many that such a small flange can be depended upon to keep the great locomotive on the track, but it should be borne in mind that the springs and equalizing bars tend to keep other sets of wheels even more firmly in place whenever any one of them is raised by an obstruction—so long as they are not all raised at once, which only a very large obstruction could cause.

The conical tread is useful in going around curves. There is an inch or more of side play between the flanges and the rails. And whenever the wheels strike a curve there is a tendency for the flanges to "hug" the outer rail, due to centrifugal force. This brings the largest diameter of the conical tire over the outer rail and the smaller diameter, of the opposite wheel, over the inner rail; the outer rail is longer than the inner one, and slipping is thus prevented.

So much for the running gear. Now let us examine the more vital parts of the engine.

CYLINDERS AND VALVES. Most locomotives are equipped with simple high-pressure cylinders, not much different from those used in the stationary engine, shown in Fig. 38.

Cylindrical slide-valves are, however, more commonly used on modern locomotives than the simple D-valve, and the cylinder castings are rather complicated. Fig. 81 shows an enlarged view of the two cylinders, the valve-chests and the steam passages. It also shows the method of fastening the cylinder castings to the frame and to each other. It will be seen that there are heavy "lugs" cast on the inner sides of the cylinders by means of which they are securely bolted to the frame.

Above the cylinders—but in the same casting—are the circular steam-chests and two sets of passages, one for the entrance of live steam, indicated by an arrow flying toward the right, and another set for the exhaust steam indicated by an arrow flying toward the centre, and afterward upward into the exhaust pipe.

The curved parts of the castings are fastened to the under side of the smoke-box and the openings connect with steam-pipes above.

There are two vertical exhaust passages, side by side, where the castings attach to the smoke-box and

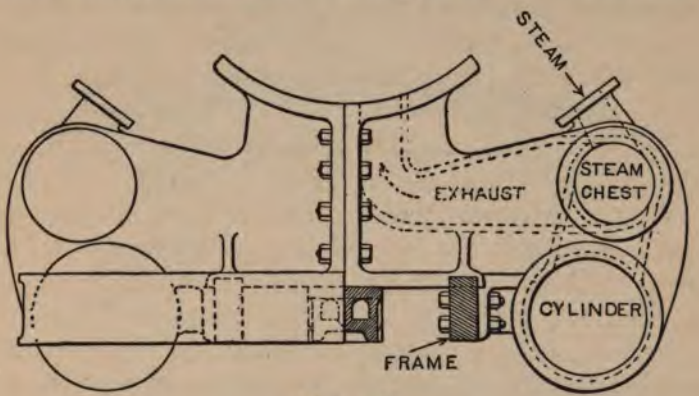

FIG. 81

exhaust-nozzle. These are not round but semicircular, as shown at the bottom of Fig. 76. The exhaust-pipe covers both of these openings; so both cylinders finally exhaust through a single exhaust-pipe. The whole combination shown in Fig. 81 is called "the saddle."

The steam passages to and from the cylinders are more clearly shown in Fig. 82. A cylindrical slide-valve, with inside admission, is here shown in middle position with reference to the ports. Steam enters through a wide opening, in the middle, and to either end of the cylinder according as the valve is moved to the right or left and the corresponding port opened.

Suppose, for example, the valve is moved to the right far enough to uncover the annular opening at that end. It is plain that steam will then rush into the right-hand end of the cylinder. At the same time the left port will be uncovered and exhaust steam from the left end of the cylinder will pass into the space marked

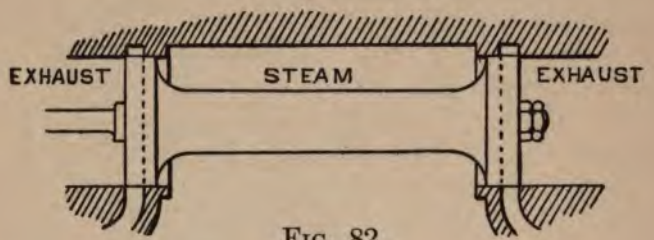

FIG. 82

exhaust, at the left end of the valve. From here it connects with the exhaust passages shown in Fig. 81.

It will be noted that there is a certain amount of lap at both ends of the cylindrical valve—on the inside. If the valve were arranged for outside admission, and inside exhaust, the lap would be on the outside as it is in the case of the simple D-valve shown in Fig. 38. A cylindrical valve for inside admission moves in exactly the opposite direction from one for outside admission; but this is easily arranged by a proper setting of the eccentric or return-crank, as the case may be.

Steam is taken from the highest part of the steam-dome and conducted to the steam-chests through a steam-pipe, inside the boiler, which branches to the two cylinders, inside the smoke-box.

Fig. 83 shows the throttle-valve, at the inner end of the steam-pipe, by means of which the supply of steam is regulated by the engineer.

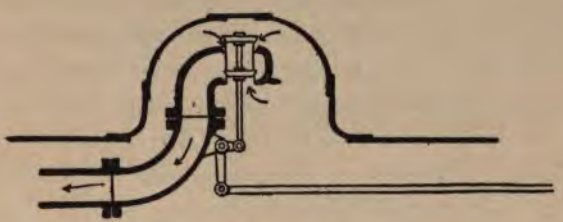

FIG. 83

The throttle-valve is of the balanced type, and is very accurately fitted. A short vertical rod attached to the valve connects with a bell-crank which is operated by a horizontal rod leading to the engine-cab. This rod passes through a steam-tight gland and is moved back and forth by means of a hand lever provided with a device for setting at various points as shown in Fig. 83A. By this means the throttle-valve may be moved much or little, and set at any desired point.

FIG. 83A

THE VALVE-GEARS. The Stephenson link motion was formerly used on all locomotives; but, inasmuch as it required two eccentrics for each cylinder, on the forward driving-axle inside the frame, it was cumbersome and rather inaccessible. Moreover, as boilers became heavier, more bracing was needed

and less room was left for eccentrics and rods under the boiler. Nearly all modern locomotives now use outside valve-gearing.

THE WALSCHAERT VALVE-GEAR. The Walschaert gear, or some modification of it, is in most common use to-day. Walschaert was a Belgian mechanic who never seems to have risen higher in employment than shop foreman, but his invention has proved to be a most valuable one. The Walschaert gear requires but one eccentric. The link is suspended on a central axis and has only an oscillating motion.

Instead of connecting directly with the valve-stem the radius-rod connects with a vertical lever-arm, which is connected with the valve-stem near its upper end, and with the cross-head, or connecting-rod, at its lower end. This is called the lap and lead lever. Through its action, a different motion is given to the valve from that produced by an eccentric alone.

Fig. 84 shows a modification of the Walschaert valve-gear that is much used on modern locomotives. It is known as the Kingan-Ripkin valve-gear device. James B. Kingan and Hugo F. Ripkin, of Minneapolis, Minn., are the inventors. It differs from the original Walschaert gear in the motion that is given to the lap and lead lever. Instead of being connected with the cross-head, the lap and lead lever, *G*, is here joined to the connecting-rod by means of a lever-arm and link. The swaying of the connecting-rod has the effect of hastening the motion of the valve at certain points of the stroke, thus giving a more ad-

vantageous movement to the valve, especially for the starting of heavy trains.

The link, *A*, is supported on a bracket at the side of the boiler by means of a trunion attached to the flat side. The shape of the working side of the link, turned toward the boiler, is indicated by dotted lines; it is hollowed out and fitted with a sliding-block attached to the radius-rod, *B*. The radius-rod is prolonged past

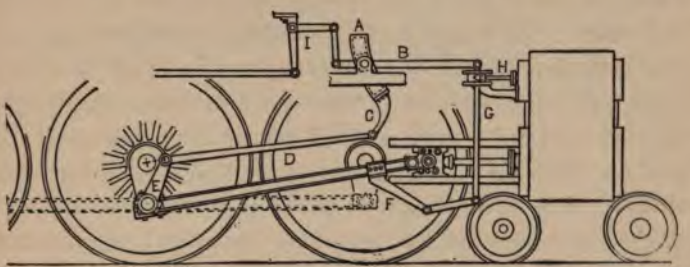

FIG. 84

the link and connected with a shifting device by means of which it can be raised or lowered as required.

In actual practice this shifting device is usually turned the opposite way from that shown in the figure, but its action is the same as just described. The shifting device is, of course, connected with the reversing lever in the cab. Attached to the lower end of the link is an arm, *C*. This arm is connected with the "return-crank" by means of a rod, *D*.

The return-crank, *E*, by means of which motion is given to the link, acts like an eccentric. It is an in-

genious device for getting an eccentric motion where neither an eccentric nor a short crank can be used. Its hub is made fast to an extension of the crank-pin and the crank-pin end of the return-crank is brought to a point corresponding to the correct position of the centre of an eccentric. The motion given to the link is exactly the same as would be produced by an eccentric, with a throw indicated by the dotted lines, below *E*.

If the device appears somewhat cumbersome, it should be borne in mind that the position of the main crank and connecting-rod prevent the use of a simpler device. If the valve-stem were connected directly with the radius-rod, *B*, the motion would be direct and simple. By shifting the radius-rod to the top or bottom of the link, full motion forward or backward is produced through the action of the return-crank. Intermediate positions give practically the same motion as would be produced by the "hooked-up" Stephenson link motion.

The return-crank is set for neither lap nor lead, but the modified motion given by the other parts of the mechanism produces a constant lap and lead for all positions of the radius-rod.

In Fig. 84 the connection is arranged for a cylindrical slide-valve with inside admission, and the radius-rod is set in its neutral position. Let us now suppose that the radius-rod is changed to its lowest position and the locomotive is running forward, the valve would be thrown to the right, and, with inside admission, steam

would be flowing into the right-hand end of the cylinder. The connecting-rod and its attachments would be moving toward the left, and the valve-rod, *H*, would be given a motion that would be the resultant of that produced by the return-crank and the connecting-rod attachment.

At this particular moment, the link-block would still be moving slightly toward the right while the lower end of the lap and lead lever would be moving rather rapidly toward the left. The attachment of the valve rod is so near the top of the lap and lead lever that the resultant motion of the valve rod would be very slight and toward the left. In other words, the valve would be starting to cut off the steam even though the link motion alone would tend to hold the valve wide open. The motion of the valve would be slight, however, until the stroke had proceeded to its last quarter. Then, both the backward motion of the link and the motion of the lap and lead lever would combine to close the valve very quickly and produce a cut-off at the right point. As the connecting-rod sways up toward a horizontal position, the end of the arm attached to it moves toward the left faster than the cross-head. This hastens the cut-off over what it would be were the lower end of the lap and lead lever attached to the cross-head, as in the regular Walschaert gear. Moreover, for the beginning of the stroke the Kingan-Ripkin device gives a more rapid and timely opening of the port than would occur if the connection were with the cross-head instead of the connecting-rod.

Guides. Fig. 85 shows the method of attaching the cross-head guides of a locomotive to the cylinder-

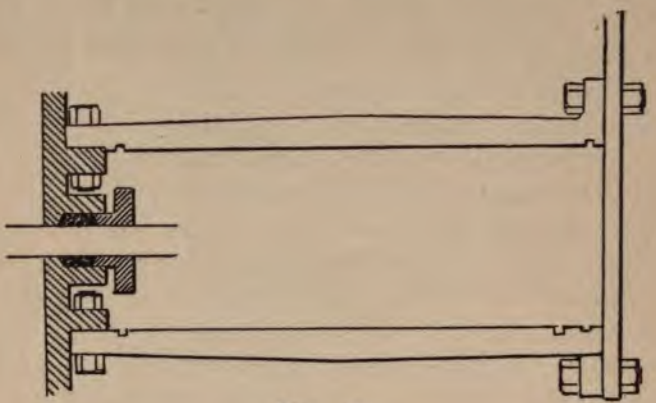

Fig. 85

head at one end and to a spanner connected with the frame at the other.

The Steam-Gauge. An important accessory to all steam-boilers, and especially to the locomotive, is the steam-gauge. Fig. 86 shows the construction of a common form of this device. A flattened tube, bent into the shape shown in the central part of the figure, is connected with the boiler at its open end and with a short rod at the other. The rod connects with a lever carrying a toothed segment, which engages with a pinion on the shaft which carries the index hand, as shown at the left. The index hand passes over a dial on which are marked figures corresponding to boiler pressures to be indicated.

As steam, under pressure, is admitted to the bent tube, it tends to straighten it; the motion is communicated to the index hand and the pressure shown on the dial. The higher the pressure the greater will be the tendency to straighten the tube. By marking the disk

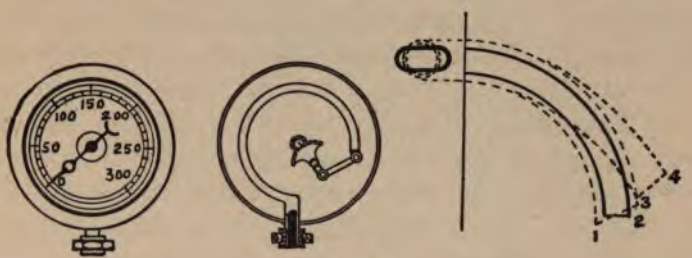

FIG. 86

to correspond to known pressures, the device can be made to show just what the steam pressure in the boiler is at any time.

The action will be better understood after an examination of the diagram at the right, which is on an enlarged scale. At the left of the vertical line, is shown a cross-section of the flat tube, and, in dotted lines, the same tube distended to a full circular cross-section. At the right, a portion of the tube is shown, as it appears in the central figure. Now suppose it to be distended to a circular cross-section. One side would be moved to the left, and on the other side to the right, as shown by the dotted lines. The end would, however, have to take the position shown at 3 and 4, rather than at 1 and 2, for the lines must remain of the

same lengths as in the original position, and this could not occur without distortion, unless the end of the tube were allowed to move toward the right.

The arrangement for transferring the movement of the bent tube to the index hand is such that an imperceptible movement of the end of the tube causes a movement of the index hand that may be clearly seen. In the manufacture of gauges the figures on the dial are first established by actual tests, with known pressures, and parts that have proved to be of the correct dimensions are then duplicated. All gauges are, of course, carefully tested before being put on the market.

THE INJECTOR. Another convenient device in use on all locomotives—as well as in marine and stationary work to some extent—is the injector. It is a means of forcing feed water into the boiler without the aid of a force-pump.

Injectors are made in various forms, but the principle may be explained by the aid of Fig. 87, which is

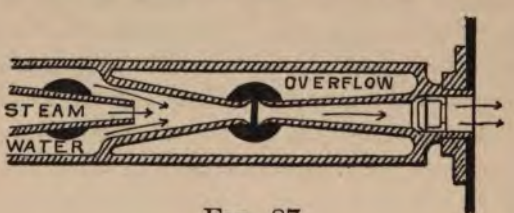

FIG. 87

merely a diagram, lacking some structural details. The injector is made up of a set of tubes and nozzles so arranged that a powerful jet of steam carries water

along with it, and forces it through an opening into the boiler. At the extreme left, Fig. 87, is shown a steam-nozzle passing through a larger tube connected with a water supply pipe. The end of the steam-nozzle enters another one, somewhat wider, which is separated by a small gap from a third nozzle, smaller than the others, turned in an opposite direction. At the base of the third nozzle there is a check-valve opening toward the boiler. Surrounding the two nozzles, last mentioned, is an overflow space connected with a discharge pipe. High-pressure steam is discharged through the first nozzle into the second. This draws water along with it. The mixture is forced across the gap into the third inverted nozzle and thence through the check-valve into the boiler. Only a limited amount of water can be carried by the steam-jet, but its action is so rapid that a sufficient flow can be maintained to supply the boiler with feed water—even without constant use. The overflow gap is useful in allowing surplus water to be discharged through another opening. Likewise, if the main supply of water is less than the steam-jet will carry, water from the overflow will be drawn through the gap and forced into the boiler. Injectors in actual use have, of course, carefully adjusted valves and cocks to regulate the supply of steam and water.

THE POP SAFETY-VALVE. The ordinary safety-valve with a weighted lever, cannot, of course, be used on a locomotive because of the motion; so springs are used in place of weights and the lever is generally dispensed with.

Fig. 88 shows the general construction of a spring or pop safety-valve. A conical valve is kept on its seat, against ordinary steam pressure, by means of a stout coil spring, acting directly. In case the steam pressure exceeds the safety limit, to which the spring is carefully adjusted, the valve is forced up and the steam escapes. When the boiler pressure is relieved to the point where the spring will close the valve, it is again closed.

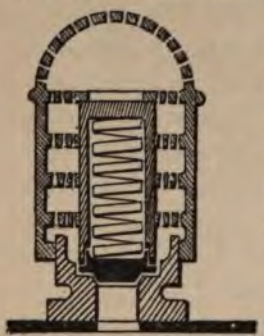

FIG. 88

Whenever the valve is raised there is an immediate release of pressure at that point which would allow the valve to drop only to be immediately raised again, if some device were not used to prevent it. This "chattering" is prevented by making the valve of the shape shown in the figure. Just above the conical part there is a flange which rests on a flat seat when the valve is closed. When the valve is raised by excessive steam pressure the escaping steam has to pass between this flange and its seat and the valve is thus held open until the boiler pressure has dropped a sufficient amount to allow the valve to remain closed for a time. Outside of the valve and the cylinder containing the spring, there is usually a "muffler" or hollow vessel filled with holes through which the steam escapes more gradually and quietly than it otherwise would. Here, again, it must be understood that the figure is only meant to

show the principle of the spring safety-valve and is not exactly like any in actual use.

THE STEAM-WHISTLE. An important accessory to all locomotives, as well as to most other steam plants, is the whistle. It consists of a hollow bell or short tube, closed at one end, against the lower edge of which a violent steam-jet passing through a circular slit is directed.

Fig. 89—again only a diagram—shows the construction. Steam comes from the boiler through a vertical pipe which connects with an enlargement surrounding a smaller pipe which connects directly with the narrow slit below the whistle. A conical valve opens from the enlargement of the steam supply pipe into the smaller pipe. The steam pressure on top of the valve keeps it tightly closed except when it is desired to blow the whistle. The valve has a stem which passes through close-fitting openings at the bottom, as shown. Hinged on the outside is a bent lever which rests lightly on the valve-stem. The whistle is operated by means of a cord or rod running from the long arm of the lever to the engine cab. A spring keeps the lever from pressing too hard against the valve-stem when not in use. Formerly steam-whistles were made with an even circular edge all around the bottom of the "bell," but they are now

FIG. 89

more often cut at an angle as shown in the figure. Often the bell is divided into two or more compartments of different lengths, each with its own separate mouth. Each compartment produces a different tone, which should of course be adjusted to harmonize with the others.

Safety-valves and whistles are usually connected with a small steam-dome near the back end of the boiler, not far from the engineer's cab.

A complete description of a modern locomotive would require a larger book than this to contain all that should be said about its many details. It must be understood that what is here given is only an introductory account of its principal features.

Locomotives are of many types and sizes, according to the work they are intended to perform. A fast passenger locomotive, with high wheels and comparatively short stroke, would be poorly fitted to handle heavy freight-trains, or to do switching in a railroad yard. The tractive power of a locomotive is limited by its adhesion to the rails; and it is, therefore, desirable to throw as much as possible of the weight on the driving-wheels. In switching engines, the whole weight is often carried on the drivers, of which there are usually many of small diameter.

The diagrams in Chapter I show how the principle of the lever is employed to exchange speed for power by using small driving-wheels and a long stroke for engines employed on mountain sections, and for switching, while high wheels and a shorter stroke are

employed for fast trains. Where several sets of driving-wheels are used, some of them are often without flanges. These serve to increase the tractive force without increasing the friction in going around curves.

The driving-wheels of locomotives are always firmly keyed to the driving-shafts; and the cranks, on opposite ends of the shaft, are placed at an angle of ninety degrees with each other, to prevent stopping on dead centres.

CHAPTER VI

THE STEAM-TURBINE

About two thousand years ago Hero of Alexandria constructed a device which worked on much the same principle as the modern steam-turbine. It consisted of a hollow metallic sphere with tubular arms, as shown in Fig. 90. The sphere was suspended over a

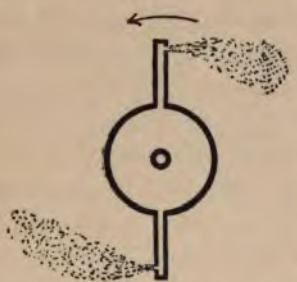

Fig. 90

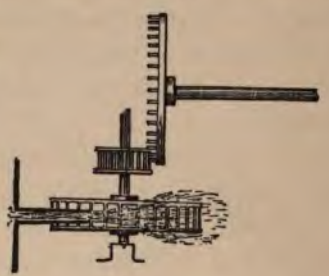

Fig. 91

small boiler by means of a hollow axle which connected with the boiler through a tube contained in one of the supports. The tubular arms were closed at the outer end, but had small openings in the sides, as shown in the figure. These openings were in corresponding sides of the two tubes with reference to rotation, and at right angles to the axis. Reaction from the escaping steam caused the globe to spin around in the direction indicated by the arrow, but it had very little power.

No attempt seems to have been made, at that time, to further develop this device. Hero's invention was often referred to in the nineteenth century as an unsuccessful attempt to utilize the power of steam, and the failure was attributed to a lack of understanding of correct principles. Watt's success in utilizing the expansive force of steam in cylinders fitted with movable pistons closed men's eyes for a hundred years to the equally useful principle that was first applied, in an imperfect way, by Hero.

About three hundred years ago an Italian named Branca constructed a device, that was no more successful than Hero's, which involved in its action another principle that has been applied in the modern steam-turbine.

Branca's device is illustrated by Fig. 91. It consisted of a wheel with vanes, like a paddle-wheel, against which a steam-jet was directed. The wheel was made to spin around; and illustrations which have come down to us show a train of wheels and axles being moved by the motor-wheel. Apparently no more power was developed than was needed to drive very light idle machinery.

With a properly shaped nozzle for the escape of the steam, Hero's engine should have developed a considerable amount of power, in rapid revolution. Branca's device lacked both a nozzle of proper shape and suitably shaped blades. It is probable, too, that the wheel was not mounted and geared up in a way that would have permitted of the very high speed necessary to develop power as an impulse turbine.

Nozzles and Steam-Jets. Before taking up the description of modern steam-turbines, let us study, briefly, the action of steam as it escapes through orifices and nozzles. Fig. 92 shows a jet of steam discharging from a hole in a boiler without any directing-

Fig. 92

Fig. 93

nozzle. It spreads, almost immediately, into a cloud of steam capable of exerting no force. At the moment of its escape, however, it would be found, if measured, to have an outward pressure equal to a little more than one-half the boiler pressure on a similar area—fifty-eight hundredths of the original pressure—to be more exact.

Now, if, instead of a mere hole, a short nozzle, of the shape shown in Fig. 93, be used, the jet of steam will proceed in straight lines for a considerable distance.

Nozzles should always have a well-rounded approach to the throat, or narrowest part. The flare and length of the cone are governed by the pressure of the steam to be discharged, but for ordinary pressures the shape will not differ very much from that shown in Fig. 93. In passing the very short distance between the approach and the outlet of such a nozzle high-pressure

steam acquires a velocity greater than that of a bullet discharged from a modern rifle.

Steam at two hundred and fifteen pounds pressure will discharge into a vacuum from the mouth of a properly shaped nozzle at the rate of over four thousand feet per second, and into the air at the rate of about three thousand feet per second.

It is difficult to understand how such great velocity can be acquired, almost instantly, but the fact can be demonstrated; we know that steam in the boiler has no velocity and there are methods by which the velocity of a jet may be readily calculated. The actual energy of the steam is really developed in the nozzle, in this case, and is imparted to the molecules as they are discharged from the mouth of the nozzle. The heat of the steam causes rapid expansion which takes place in the direction of the axis of the nozzle. The energy of the steam is transformed into momentum of its particles in much the same way as the volume is increased in the case of the reciprocating engine. The flare of the nozzle allows of a small amount of lateral expansion while the jet is gathering force in the direction of its axis.

Steam, like all other substances, has weight. When it first begins to generate, an ordinary boilerful weighs not more than a pound or two. At a pressure of four hundred and seventy-five pounds per square inch a cubic foot of steam weighs a pound, and at two hundred pounds to the square inch—not an unusual pressure for modern boilers—it takes about two cubic feet to weigh a pound. Now, it does not take a pound of steam very long to escape from a nozzle, and in do-

ing so it acquires as much momentum as any other substance of the same weight moving at the same velocity.

A lead bullet moving as fast as a steam-jet employed in driving a modern impulse steam-turbine would pass through an oak target more than two feet thick; a quantity of steam of equal weight will escape in one or two seconds. The main difference is that the bullet acts almost instantly while the steam-jet takes a little more time to get in its work. The action of a steam-jet may be compared with that of a machine-gun where the bullets, like the molecules of steam, follow each other very rapidly. The efficiency of a machine-gun is measured by the weight of metal that it can discharge in a given time, and the same principle applies in the case of the steam-jet. Though the weight of a molecule of steam is extremely small the number of molecules that can be discharged in a second of time is beyond computation.

When a body, large or small, has once been set in motion, it takes force to stop it or to change its direction. The molecules of steam in a steam-jet, when they have once been discharged from a nozzle, tend to move forward in straight lines—like a bullet from a rifle. They will exert force on anything that tends to stop them or to change their direction.

Now, let us see how the energy of steam that has been generated in a boiler and transformed by a nozzle into momentum, can be utilized in driving machinery.

Suppose that a steam-jet from a properly shaped nozzle be directed against the surface of a smooth

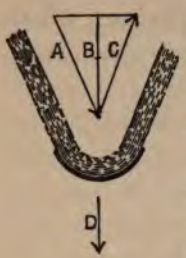

FIG. 94

metallic vane, as shown in Fig. 94, and that no change of velocity takes place as it slides along the surface and is discharged from the right-hand edge.

So long as the vane remains at rest, no power will be developed, but there will be a tendency for the vane to move in the direction of the arrow due to the resistance of the jet to any change in the direction of its motion.

If the vane be free to move, the jet will still leave the right-hand edge at the same speed with which it enters at the left-hand edge; but, as the vane moves in the same direction as the jet the speed of the jet over the surface of the vane will be less than when the vane is at rest. During this slowing down of the jet, with reference to the vane, power will be developed proportionate to the weight of the steam discharged. It is like catching a ball by moving the hands in the direction of the motion. The more sudden the stop the greater will be the shock and heat, but the ball will exert the same amount of energy whether brought to rest suddenly or more slowly.

Whenever mechanical energy is transmitted from one moving body to another two different forms of energy result, mechanical energy and heat. The sum of the two is always exactly equal to the mechanical energy given up by the first body, but the heat generally represents waste. A quick stop always results in an undue proportion of heat and consequent loss of mechanical energy.

In the case of the impulse turbine it has been found that the most efficient "rotors" are those that have a rim velocity a little less than one-half that of the steam-jet. In Fig. 94 let the arrow, *A*, represent, by its length, the velocity of the jet as it approaches the vane. Now, inasmuch as the approach is at an angle, the tendency to move the vane in the direction of the arrow, *D*, will be something less than it would be if the movement of the jet and the vane were in exactly the same direction. As a matter of fact the force exerted on the vane will be proportional to the vertical component of *A*, represented by the length of the vertical line, *B*. One-half of *B*, or *D*, will be the best speed for the vane to absorb the impulse of the jet, *A*.

As to the motion in the direction of the arrow *D*, the vane is moving about half as fast as the jet; and the motion along the surface of the vane is, consequently, only about half the actual velocity of the jet. As the jet leaves the right-hand edge of the vane it will therefore have practically no absolute motion either in the direction of the vane or in the opposite direction, for it is moving upward with reference to the vane at about one-half its original speed, while the vane itself is moving in the opposite direction at the same rate of speed.

The De Laval Impulse Turbine. The first successful steam-turbine was constructed by a Swedish engineer named De Laval. His first machine was constructed on the principle of the Hero engine; and it developed sufficient power to operate a cream separator. De Laval soon abandoned this type, however, and constructed a turbine on the principle of Branca's engine.

After some experimentation, De Laval brought out an impulse turbine that developed a considerable amount of power. He used a rotor, or impulse wheel, in the form of a disk with buckets or vanes, like that shown in Fig. 94, arranged at the outer rim. One or more flaring nozzles, cut off at an angle so as to come as close as possible to the revolving buckets, were arranged so as to direct jets of steam against the vanes in the same way that we have just been considering.

Fig. 95 shows a De Laval nozzle and a set of vanes in their usual position. The nozzles are fitted with throttle-valves, so that they can be opened or closed according as one or several are needed to produce the required amount of power.

FIG. 95

We have seen that the proper speed for the vanes of an impulse turbine is about one-half that of the steam-jet, and that steam-jets from high-pressure boilers have a velocity of from three to four thousand feet per second.

In order to have buckets move at the rate of fifteen hundred or two thousand feet per second, mechanical difficulties must be overcome. In order to have a rim velocity of fifteen hundred feet per second, a disk, one foot in diameter, must make in the neighborhood of five hundred revolutions per second. This is too high f

speed for safety, even with the use of the best materials. The centrifugal force, in such a case, would be so great that a vane weighing only a few ounces would exert an outward pull of several hundred pounds; and in case anything broke loose, great damage would be likely to result.

Though the greatest efficiency is attained, as we have seen, when the rim velocity of the rotor is nearly one-half that of the steam-jet, very good results are obtained with rim speeds of a little more than one-third the speed of the jet.

Small rotors have been run with a rim speed of more than one thousand feet per second, and speeds of six and seven hundred feet per second are not uncommon, in the De Laval type of steam-turbines. A rim speed of seven hundred feet per second means nearly fourteen thousand revolutions per minute for a rotor one foot in diameter.

Rotors as small as four inches in diameter are used on De Laval turbines developing one horse-power. Five horse-power De Laval turbines have rotors about one foot in diameter.

It is hard to realize how such a small rotor can be made to develop this amount of power with only two or three jets of steam playing upon it. But let us consider for a moment the number of impulses that will occur in a second of time on a rotor one foot in diameter, fitted with three nozzles, revolving at the rate of fourteen thousand revolutions per minute.

Such a rotor would have at least one hundred vanes, and each nozzle would play on at least three vanes at one time. We would have, then, nine hundred separ-

ate impulses at every revolution of the rotor and twelve million six hundred thousand in one minute. Dividing by sixty gives us two hundred and ten thousand impulses per second. Though each separate impulse be very small, two hundred and ten thousand of them will amount to a great deal. Here we have the secret of the great power of the steam-turbine—a great number of small impulses combined with high velocity.

Fig. 96 shows a section of a De Laval rotor, on the

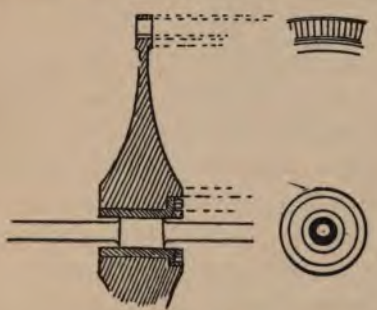

FIG. 96

FIG. 97

left, and a partial side view on the right. The vanes are shown at the top, in mere outline. Fig. 97 shows them in detail, and the method by which they are attached to the rotor.

Each vane is made from a separate drop forging of steel, and they are fitted together and attached to the rotor with the greatest care. Apertures are drilled and milled in the edge of the rotor, as shown at the extreme right in Fig. 97. The blades are then fitted as shown.

It will be noted that the rotor is much thicker near the shaft than near the circumference, as shown in Fig.

96. This is to resist the tendency to fracture, due to high velocity, which is greater near the axis than elsewhere.

The motion of a rotor of the De Laval type can best be compared with that of a humming top. In order to insure smooth running the greatest possible care must be taken to have the rotor well balanced.

Here, again, is a mechanical difficulty to be overcome, for, with separate vanes fitted to the rim, perfect balance is difficult to attain. If the centre of gravity of the rotor and its numerous blades is a hundredth of an inch from the centre of rotation serious vibration will occur at the very high speed employed. But at humming-top speeds revolving bodies tend to rotate about their centres of gravity rather than about any fixed axis, and this fact is taken advantage of in mounting rotors of the De Laval type. Instead of heavy shafts running in ordinary journal-boxes, light shafts with bearings some distance apart are used, as shown in Fig. 96. When the rotor passes what is called its critical speed, it begins to revolve about its centre of gravity and holds the centre of the light shaft in that position steadily. The flexibility of the light shaft allows of this amount of bending without affecting its capacity for the transmission of power.

The shaft may not be bent out of its normal position more than one or two hundredths of an inch, so no perceptible amount of distortion will generally occur. Fig. 96 shows one method of mounting a rotor on a flexible shaft—where the centre of the rotor is pierced. Fig. 98 shows another method of mounting—where there is no hole through the rotor, but where two shafts

with suitably shaped flanges are fitted to opposite sides. It may seem that such small flexible shafts are unsuited to the transmission of power and that they are out

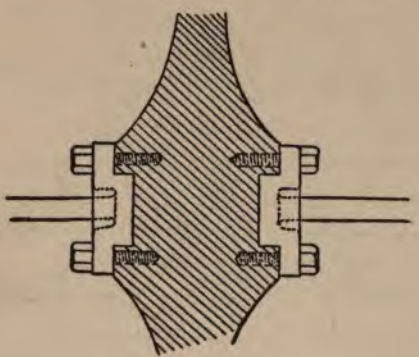

FIG. 98

of proportion to the heavy hubs of the rotors. Here, again, we should bear in mind that the high speed which makes it necessary to use strong rotors, to resist centrifugal force, allows a small shaft to transmit a great amount of power. The higher the speed, the less the diameter of the shaft may be.

A shaft half an inch in diameter will transmit as much power, in a given time, at fourteen thousand revolutions per minute, as a three-inch shaft moving slowly. This is another case where time and space are exchanged for power to good advantage.

Rotors are usually mounted in steam-tight cases, and several nozzles are often attached to the casing. Sometimes these are cast in one piece with the casing, as shown in Fig. 99. Ample provision must always be

made for a free exhaust after the steam has acted on the rotor. Otherwise it will exert back pressure

FIG. 99

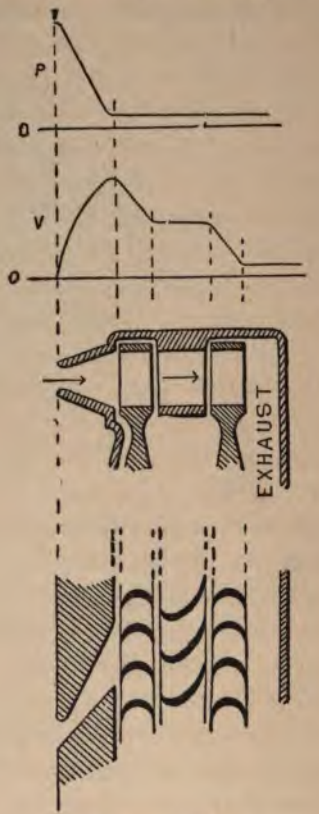

FIG. 100

and retard the rotor. Exhaust-pipes leading either to condensers or to the open air are therefore made of large size.

Fig. 99 shows two sections of an impulse turbine. One through the horizontal axis of a nozzle, and above it, another through the axis of the rotor. Above these are shown two diagrams which should be explained at this point. The top one shows how the pressure of the steam drops as it passes through the nozzle; the other shows how its velocity rises at the same time. The dotted vertical lines connect the sectional views with corresponding points in the curves of pressure and velocity. It will be noted that the pressure remains the same after the jet leaves the nozzle, but the velocity drops suddenly, as the jet enters the vanes. The problem, as we have seen, is to bring the steam-jet to rest, as nearly as possible, through its action on the vanes. In a single impulse turbine where the rotor moves at about one-third of the velocity of the jet, the steam will always retain some velocity, as indicated by the horizontal line a little above the line of no velocity, marked *o*.

Fig. 100 shows a double rotor with fixed directing vanes between. By means of this arrangement slower moving rotors may be used, and the velocity drop be divided between the two rotors.

The diagrams above show that the pressure remains practically the same after the steam leaves the nozzle, but the velocity drops one-half in each set of vanes. In passing through the fixed set of vanes, the velocity remains the same as when it left the first set of vanes, but its direction is changed so as to give the right angle of approach to the second rotor. Often the two sets of moving vanes are attached to a single rotor by a

forked section which passes on either side of the fixed vanes. In this case, the rotor may be slowed down to about one-half the velocity that would be required for a single set of vanes developing the same amount of power.

Reduction Gears. One of the greatest difficulties to be overcome in applying a steam-turbine, of the De Laval type, to commercial uses is in reducing the speed of the rotor—which we have seen must always be high—to that of ordinary machine movements.

Except for a certain class of small electric generators, there is hardly any machine that can be run at anything like the usual speed of a De Laval rotor.

Attached to nearly all such turbines, therefore, are trains of gearing by means of which the speed of the final driving-shaft is reduced much below that of the rotor. For this purpose spiral-toothed gearing is commonly used, as it works more smoothly than ordinary straight-toothed gearing. Fig. 101 shows a pair

Fig. 101

of spiral-toothed pinions, integral with the rotor shaft. They are of very small diameter and usually mesh into gear-wheels of ten times their diameter. Two sets of spiral gears, with spirals running in opposite directions, are usually placed side by side, in order that the side thrusts caused by the spiral shape of the teeth may counterbalance each other.

One reduction of this kind is usually sufficient for

running electric generators. In a case like that just considered—with one reduction in the ratio of 1 to 10—a rotor making fourteen thousand revolutions per minute may be made to drive an electric-generator shaft at the rate of fourteen hundred revolutions per minute. This would still be far too high a speed for steamship propellers, or most other purposes, but another reduction at the same ratio would be sufficient for many practical purposes.

Instead of using several reductions, by means of heavy gears, however, there are other means of reducing the speed of turbine rotors directly, which will later be explained.

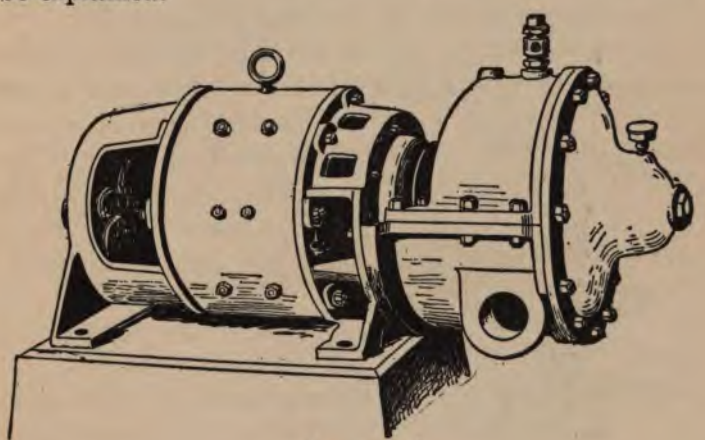

FIG. 102

Fig. 102 shows a general view of a 10-kilowatt—about thirteen horse-power—directly connected turbo-generator manufactured by the Westinghouse Electric and Manufacturing Company of East Pittsburgh, Pa.

The turbine proper is attached to the generator and is shown overhanging the foundation on the right. The large opening at the bottom is for the exhaust. The steam inlet is on the other side.

The bulging cylinder-head is so shaped to accommodate the governor which, with the other internal mechanism, is shown in the sectional view, Fig. 103.

Before the governor is studied, attention should be given to Fig. 104 which shows the rotor, with a single set of blades, and the nozzle and "reversing-chamber" in their correct positions with reference to the rotor, but, of course, independent of it. Here is an example of a practical method of employing a much lower speed for the rotor than half the speed of the steam-jet.

On the right-hand side of the rotor is shown a flaring nozzle, of rectangular cross-section, which directs the steam-jet against the vanes on that side. The speed of the rotor being much less than one-half that of the steam-jet, the steam issues from the left-hand edges of the vanes with more than half of its original velocity. This current of steam now flows into the curved channels of the reversing chamber, is turned completely around and directed against the left-hand edges of another set of vanes from which it finally escapes into the exhaust-chamber. Here we have the same effect, less a considerable amount of fluid friction,

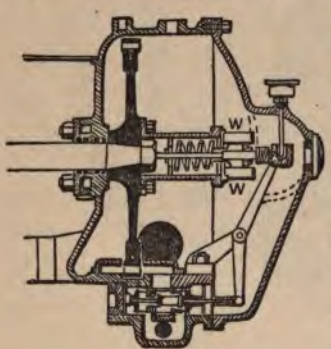

FIG. 103

that is produced by a double rotor like that shown in Fig. 100.

Referring now to Fig. 103, we see the rotor, in section, attached to the end of a stout shaft with but one bearing in sight. The other end of this shaft carries the rotor of the electric generator, without any intermediate gearing, and is supported by another bearing attached to the frame of the generator. It may be thought that this method of mounting does not make provision for vibration at high speed, spoken of earlier in this chapter. But, as will later be explained, there are other methods of providing against vibration than that employed by De Laval.

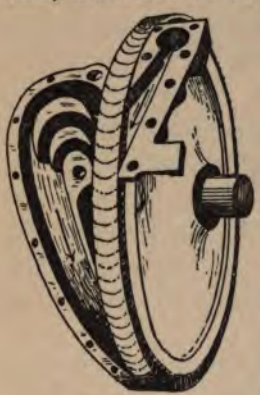

FIG. 104

In the sectional view the nozzle is shown in cross-section at the right of the lower limb of the rotor, and the reversing chamber is shown on the opposite side of the rotor.

The term "reversing chamber," as already indicated, applies to the arrangement for reversing the direction of the steam-jet, so that it may be used a second time in driving the vanes. Steam-turbines are not reversible.

THE TURBINE GOVERNOR. Just below the nozzle, Fig. 103, is shown a set of steam passages through which steam enters the nozzle.

The smaller of the two round black spots indicates the end of a steam-pipe leading from the boiler; the larger one is the exhaust passage.

Between the steam-pipe and the nozzle there is a metallic sleeve containing a small balanced cylindrical valve, operated by a horizontal valve-stem, which is connected by means of a lever to a horizontal governor attached to the hub of the rotor. The steam must pass through this valve before being admitted to the nozzle.

Whenever the rotor acquires too high a speed, the weights, *w w*, move outward; the spring is compressed and the spindle of the governor moves slightly to the right. This motion is communicated, through the lever, to the valve and less steam is allowed to enter the nozzle. Whenever the speed of the rotor gets too low the governor works in the opposite direction and more steam is admitted.

It is claimed that the speed of the rotor can thus be kept within 3 per cent of normal whether running with full load or no load.

There is a removable plug at the right of the casing; and the whole "cylinder-head" may be removed, as in the case of an ordinary reciprocating engine, whenever it becomes necessary to examine the interior. It is claimed that this little engine will run for many months without further attention than proper lubrication.

The Westinghouse Company manufacture a number of different sizes of impulse turbo-generators. The smaller sizes have no intermediate gearing for reducing the speed of the generator rotor, but in the larger sizes spiral reduction gears are used, like that already described. Reversing chambers are employed in all these engines.

Flexible Bearings. Fig. 105 shows a form of bearing that has pretty nearly superseded the flexible

FIG. 105

shaft, as a means of overcoming vibration in turbines with high-speed rotors. It is made up of several concentric sleeves of metal, the inner one of which is of good wearing material, fitting somewhat loosely into each other. There are loosely fitting studs to keep the sleeves from turning upon one another, and holes, as shown, where oil can pass into the spaces between the sleeves. When oil of the right consistency is used it forms films between the different layers. When the rotor has passed its critical speed and seeks to turn about its centre of gravity, the thin layers of oil allow of a slight movement like that already mentioned in the case of the flexible shaft.

SAFETY DEVICES. Most steam-turbines are fitted with safety devices to prevent overspeed, such as might occur in case something went wrong with the governor.

Fig. 106 shows a common form of such a device. A hole is drilled through the shaft, and in it is fitted a pin with a rounded end which is held entirely within the hole, at ordinary speeds, by means of a spring. Outside is a lever with one arm pressing against the under side of the shaft, as shown.

FIG. 106

A notch in the other arm of the lever holds one arm of a bell-crank connected, by

means of a rod, with a valve in the steam supply pipe, which closes by gravity or by means of a spring.

The centre of gravity of the pin is slight'y nearer the rounded end than is the centre of the shaft—as indicated by the small dot. The spring is so adjusted that it will hold the pin in place, at safe speeds, and allow it to move away from the centre of rotation, through the action of centrifugal force, at unsafe speeds. Whenever the end of the pin moves outside the surface of the shaft, it strikes the upper curved surface of the arm, disengages the bell-crank and allows the valve in the steam supply pipe to close; this brings the turbine to rest.

Reaction Turbines. All of the steam-turbines thus far described, except the Hero engine, have been of the kind that depend for their action on the impulse principle, the full energy of the steam-jet being developed in the nozzle and its momentum being absorbed, so to speak, by one or more sets of rapidly moving vanes.

We have now to consider a type that depends for its action on a different principle.

Hero's engine worked by reaction, and this principle has been applied in modern steam-turbines.

Charles A. Parsons, of England, brought out an engine that worked on this principle in 1884—a year before De Laval patented the modern impulse turbine.

A good illustration of the principle of reaction is that of a boy on skates throwing a ball. The more energy he employs in throwing the ball, the more he will be pushed back by reaction. Any one who has ever

discharged a rifle or shotgun with the stock against his shoulder knows that the discharge is always accompanied by a decided "kick." In large-sized field and marine guns special provision has to be made for taking up this reaction, otherwise the mountings would be quickly destroyed. In all these cases, the force exerted on the moving body is balanced by an exactly equal force of reaction which itself becomes an active force whenever the discharging body is free to move.

In the case of the impulse turbine, there is reaction in the nozzle, in a measure like that of a gun, but the rigidity of the nozzle and the frame to which it is attached prevents any motion. Now, when steam escapes from a short straight nozzle, or through an orifice like that shown in Fig. 107, it expands comparatively little during its passage. If it is then directed between blades, free to move, of the shape shown in the figure, expansion will continue and, consequently, the velocity will increase. The momentum of the steam current of course increases with the velocity and this produces reaction which tends to move the blades in the direction of the arrow at the left. As a matter of fact, the force of reaction will be exerted principally in an opposite direction to the direction of the jet when it leaves the blades; but, inasmuch as the blades are only free to move directly to the left, the force will only be effective in that direction. If we have a set of blades of the proper shape arranged in the cir-

FIG. 107

cumference of a disk, as in the case of an impulse turbine, and a number of short straight nozzles like the one shown in Fig. 107, we will have a simple form of a reaction turbine.

In almost every case in actual practice, however, the steam that escapes from the first set of blades is then conducted between fixed blades of about the same shape as the moving blades, but turned in the opposite direction. By this means the currents of steam are directed against another set of moving blades, as shown in Fig. 108. One series of fixed and movable blades after another are arranged so that the steam currents are brought into contact with many different sets before they finally escape into the open air or into a condenser.

FIG. 108

As the currents of steam advance from one set of blades to another they gain in volume, and, up to a certain point, in velocity. Thus the energy of the steam is gradually imparted to one set of blades after another until it is reduced to a point where it is no longer profitable to continue the process.

Even in these so-called reaction turbines the steam acts partly by impulse as it passes from fixed to moving blades. The term reaction turbine is employed to distinguish this class of engines from those that act by impulse alone.

In reaction turbines expansion occurs, as we have

seen, from the time the steam enters the first set of blades until it is finally discharged. More and more space must, therefore, be provided for the currents of steam as they pass from one set of blades to another.

In Fig. 108 the blades are shown farther apart in the later stages than at the beginning, but in actual practice the extra space needed is generally provided by increasing the lengths of the blades, in each successive set, until a certain limit is reached; then, the diameter of the rotor is increased, and shorter but more numerous blades are used.

THE PARSONS TYPE OF STEAM-TURBINE. The various sets of blades are all attached to the outer surface of a revolving-drum in turbines of the Parsons type. This drum, which is usually of steel finished both inside and outside to secure as perfect balance as possible, is made up of two or more sections of different diameters. The blades for the earlier stages are attached to the smallest diameter and the larger diameters correspond—as has been explained—to the later stages.

Quite as important as the rotor, and as difficult of construction, is the casing which carries practically the same number of fixed blades that the rotor does of movable blades. There must be a set of fixed blades between each set of movable blades and the next set of movable blades; the casing, moreover, must be made in two parts. Not only must the two parts of the casing be fitted together with great accuracy, but care must be taken to proportion the parts so that unequal expansion from the heat of the steam may not warp them in such a way as to bring fixed and mov-

able blades into contact with each other. It is desirable to bring the fixed and movable blades as near together as possible without touching; and it must be clear that only the most skilful mechanics can be employed in such construction.

Fig. 109, used by permission of the Westinghouse

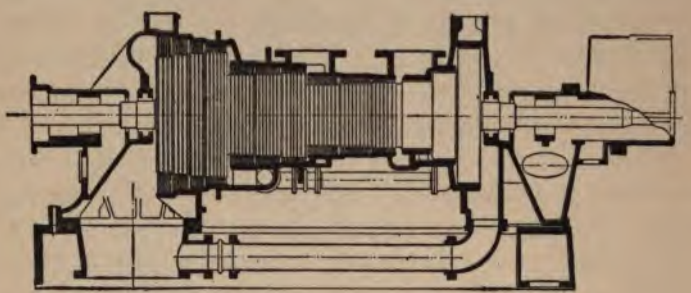

FIG. 109

Electric and Manufacturing Co., of East Pittsburgh, Pa., illustrates the general construction of a single-flow reaction turbine of the Parsons type. Steam enters the casing near the right-hand end of the rotor and passes through one set of blades after another until it finally reaches the wide exhaust passage at the extreme left.

The increasing lengths of the blades and enlargements of the diameter of the rotor, as the exhaust is approached, are plainly indicated. Near the middle of the rotor there is a by-pass inlet by means of which steam at boiler pressure can be admitted at that point whenever it is necessary to develop additional power.

In this way the main current of steam, which has spent some of its energy, can be reinforced for the purpose of handling excessive loads.

In single-flow turbines the force of the steam acting in the direction of the flow produces a great deal of end pressure on the rotor. This is overcome by "dummies," corresponding in diameter to the enlargements of the working portion of the rotor, which serve as counter-balances. These are shown near the right.

Equilibrium pipes connect the various stages with dummies of corresponding diameter, as shown in Fig. 109.

Most large turbines are connected with condensers and the better the vacuum maintained in the condenser and casing, the more efficient the turbine will be.

Figs. 110, 111, and 112, which are also reproduced by permission of the Westinghouse Electric and Manufacturing Company, show various modifications of the Parsons type of steam-turbine in use to-day.

The Combination Impulse and Reaction Single-Flow Turbine. It has been found practicable to combine impulse and reaction turbines by attaching impulse rotors to the admission end of the main rotor. Such an arrangement is shown in Fig. 110. Here a double-bladed impulse rotor takes steam, only partially expanded, directly from a nozzle chamber and delivers it to the reaction rotor on which it then acts in the same way as in the single-flow reaction turbine. It will be noted that the later sets of blades, on the reaction rotor, allow for expansion by means of extra length and greater diameter as the steam approaches the condenser.

Rotors on large reaction turbines seldom make more than seven hundred revolutions per minute, but they are often speeded higher on small combination turbines so as to give as high a speed as possible to the impulse

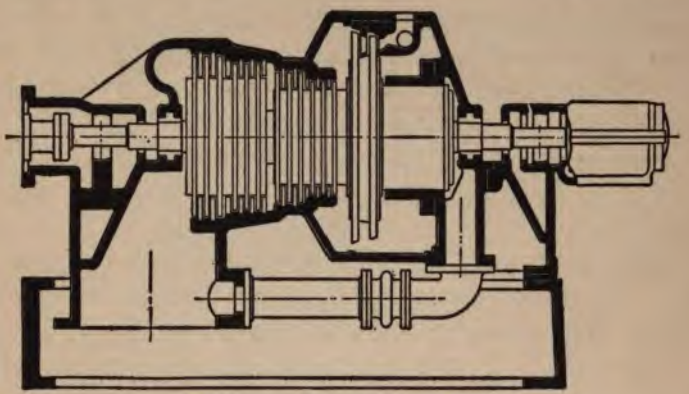

FIG. 110

blades. With steam only slightly expanded and of comparatively low velocity, the impulse rotors, which of course cannot move faster than the reaction rotors to which they are attached, can be run efficiently at much lower rim velocities than in the case of the De Laval turbines where the steam is fully expanded in the nozzle and expelled at a very high velocity.

THE DOUBLE-FLOW TURBINE. Fig. 111 shows a favorite form of combination impulse and reaction turbine where the steam first acts on a double-bladed impulse wheel and is then discharged into a chamber from which it flows both ways through reaction blading

to exhaust passages at either end of the casing. In double-flow turbines of this sort dummies are not re-

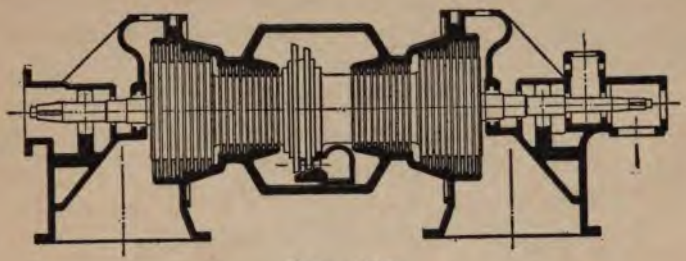

FIG. 111

quired, for the opposite flows balance each other and prevent end pressure on the shaft.

SEMI-DOUBLE-FLOW TURBINE. Fig. 112 shows what is called a semi-double-flow turbine. Here steam is

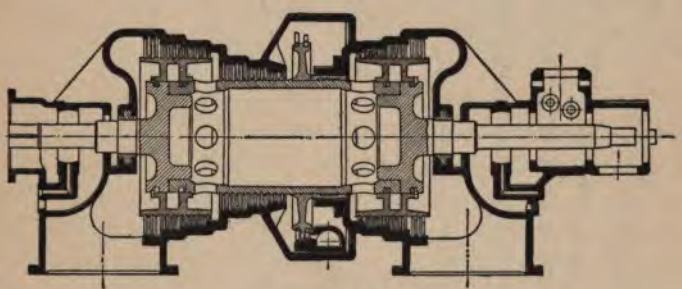

FIG. 112

first admitted to an impulse wheel and then to high-pressure reaction blading on one side. When it has ceased to act on this high-pressure blading, the current

is divided. One portion goes on acting through low-pressure blading at the end of the rotor toward which the current has been flowing, while the other portion passes through openings into the interior of the rotor, thence out through corresponding openings at the other end into another set of low-pressure blading. Here, again, a small dummy is necessary to balance the end pressure on the high-pressure blading, but the two low-pressure elements balance each other.

The method of attaching reaction blading to the rotor, employed by the Westinghouse Company, is shown in Fig. 113 and Fig. 114.

The blades are made of phosphor-bronze drawn to the proper section, heated, treated, and cut to length. The root ends, shown in Fig. 114, have a shoulder or lug, formed by an "upsetting" process, which rests in a groove of the same depth. The grooves in the rotor are dovetailed in cross-section and have a small auxiliary groove of rectangular cross-section at the bottom. The last-mentioned grooves are those in which the lugs at the roots of the blades rest. Steel packing pieces are bevelled on the ends to

FIG. 113

fit snugly in the dovetailed grooves. These fit in between the blades and hold the roots, with their lugs, firmly in place. Double wedges are used on one side of the dovetailed groove, to avoid the necessity of

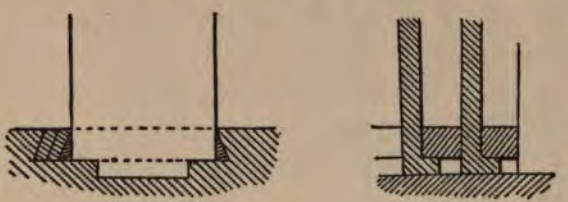

FIG. 114

perfect fitting of the packing pieces. These wedges are carefully machined and are made to fill completely the space at the side of the dovetailed groove. Nothing less than a force capable of actually shearing the metal can dislodge the blades after they are once wedged into place.

The outer ends of the blades are held apart and stayed by means of a heavy wire of "comma section." The blades are pierced by holes of comma section, and through these holes a comma-sectioned wire is threaded. After the ends are spaced exactly, by slight blows of a hammer, the tail of the comma is closed down against the body of the wire, as shown at the right, by means of pliers. The sharp edges of the comma-shaped hole cuts the tail at the right place and an effectual brace is formed, which prevents any movement of the blades.

All that has been said above about the securing of blades on the rotors applies equally to the fixed

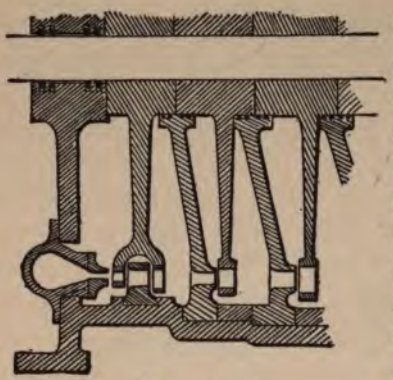

FIG. 115

blades which are practically of the same number and shape as the movable blades. The fixed blades are secured to the inside of the casing, or cylinder in which the rotor revolves, and they must be just as carefully spaced and adjusted as the movable blades, in order that the fixed and movable sets may come very close together without anywhere touching even under slightly unequal expansion, which sometimes occurs.

Only the best of workmanship can be allowed on rotors and casings in the manufacture of steam-turbines.

THE MULTIPLE-STAGE TURBINE. Fig. 115 shows a form of impulse turbine which is constructed on the principle that steam, escaping from a short straight orifice, loses only about one-half of its pressure—with a corresponding increase in volume. Instead of allowing full expansion in the nozzle, as in the De Laval type, the steam is first directed through a straight nozzle onto a double-bladed impulse wheel. On the same shaft as this impulse wheel are keyed several other impulse wheels, each one of which has longer blades than the one before it. Between the different impulse wheels, are steam-tight diaphragms so that the steam really passes into another closed vessel, after

passing through each successive wheel or rotor. Another series of straight nozzles then directs the currents to the next rotor. In this way the pressure is gradually stepped down and the velocity of the steam currents is at no time nearly so high as in turbines of the De Laval type. Much lower rotor speeds can thus be used; and it is often possible to connect generator rotors and other working parts with the turbine rotor shaft, directly. Fig. 115 is only a diagram for the purpose of showing the principle upon which this type of turbine works. The various parts are not accurately drawn to scale. Three straight nozzles—only one of which is shown in the figure—are generally used at the first stage. They are so arranged that one or all can be used at a time—as the load may require. Only three complete stages are indicated in the figure, but it is plain that the same system can be extended indefinitely. Six or more stages are commonly used.

It will be seen that the hubs of the rotors fit closely together on the same shaft, and that the diaphragms are dish-shaped with holes in the middle large enough to admit the hubs of the rotors. The hubs are accurately machined, and packing-rings are used to make steam-tight joints between the hubs and the disks. Inasmuch as steam escapes from straight nozzles with fifty-eight per cent of its original pressure and a corresponding increase of volume, each successive compartment must be supplied with something like twice the amount of nozzle capacity of the preceding one. In the diagram, this is indicated by enlarged cross-sections from left to right. In actual practice, however, the

increased capacity is generally secured by increasing the number of nozzles between the different compartments—from left to right.

If three nozzles are used to admit steam from the boiler to the first rotor, six openings of about the same size, in the first diaphragm opposite the buckets of the second wheel, would be sufficient for the next stage. Double this number, or four times the original number of nozzles, would, in the same case, be needed for the third stage, and so on. The openings in the diaphragms correspond, in a way, to the fixed blades in a reaction turbine, but they do not, except in the last stage, extend to anything like the full circumference of the disk.

Reaction turbines work well at comparatively low pressures; and it has been found worth while to install them, in many cases where reciprocating engines are in use, between low-pressure cylinders and condensers. In this way the heat contained in ordinary exhaust-steam may be utilized in further expansion, and made to add materially to the power of the steam plant.

While great skill is required in the manufacture of turbine engines, they are, when properly constructed, very easy to maintain. No internal lubrication is required, so the water of condensation is always free from oil and ready to be again used in the boiler. Absence of heavy reciprocating parts insures smooth running at high speeds; and the power that can be developed in a small-sized turbine, as compared with a reciprocating engine of like weight, is surprising.

Marine Turbines. Steam-turbines have in recent years come to be preferred to reciprocating engines in certain classes of marine work, especially for driving fast ocean liners.

The fastest ships are thus equipped, and a great saving of space over that required for reciprocating engines is thus brought about. The rotors on some of the big liners are 12 feet or more in diameter. The number of blades—ranging in length from about 2 inches to nearly 2 feet—runs into the hundreds of thousands, and in some cases above one million. About the only disadvantage in the use of the steam-turbine, for marine work, is that turbine rotors are not reversible. So in great liners "astern turbines" are installed for stopping and backing.

The largest liners have four or more separate propellers; and, inasmuch as astern movements, though often necessary in manœuvring, are not to be compared with ahead movements in importance, only one or two of these propellers need to be equipped with the astern turbines. Astern rotors are often attached directly to ahead rotors, in which case one is always idle while the other is working.

We have seen that the steam-turbine is impelled by the momentum of the light molecules of steam moving at high velocity. Though the impulse given to a single blade is small, a million blades moving rapidly develop tremendous power.

Though we can hardly conceive of steam as having weight, no amount of velocity without weight, or substance, would produce an ounce of energy. It may be

of interest to state that the actual weight of steam that passes through the seventy thousand horse-power turbine equipment of a great ocean liner amounts to upward of three hundred tons per hour.

It is, indeed, strange that a principle like that employed by Hero and Branca so long ago and pointed to by men of science for hundreds of years as incorrect, should, in these later years, have come to be recognized as equal in importance to that employed by Watt and his followers.

It should not be forgotten, however, that both reciprocating and turbine engines depend for their action on the expansive power of steam: in one case through direct pressure, and in the other case through the momentum of steam particles caused by rapid expansion. In both cases the expansion is caused by the heat which has first been generated by combustion of fuel under the boiler. This heat is first conveyed to the water in the boiler and finally into the steam which moves the engine.

Let no one who has followed the descriptions and explanations of this and the previous chapters, but who has not gone into a thorough study of thermodynamics, think that he is fully equipped with knowledge of the steam-engine. Larger volumes than this have been devoted to discussions of single features, like valve-gears; and the abstruse works that deal with heat and thermodynamics fill whole shelves of technical libraries.

While it is true that every well-equipped mechanical engineer should have a thorough knowledge of physics, mathematics, and mechanics, it is also true that many

of the important improvements of the modern steam-engine have been thought out by untechnical engineers and mechanics. When once an important advance in the understanding of principles has been made, and machines put into use, it is often comparatively easy for ingenious but untechnical men to see where changes in details can be made to advantage.

Saving of weight and space, smooth running, and economy of operation and maintenance, all tend to distinguish the steam-turbine as the steam-engine of the future.

CHAPTER VII

MEASUREMENTS OF POWER

FORCE, energy, power and other like terms are often used interchangeably, but there is really a great difference in their technical meaning.

FORCE. Force is properly defined as any cause that produces, stops, changes, or tends to produce, stop or change the motion of a body. Gravity is a familiar example, and the pound has been adopted as the common unit of force. We speak of the "draw-bar pull" of a locomotive as so many thousand pounds, and of the pressure of steam as so many pounds to the square inch. The power of an engine is quite a different matter. Before defining power, however, some other terms should be explained.

WORK. Work is a term used to denote something accomplished by the application of force. It is calculated by multiplying the force by the distance through which it has moved against a known resistance. The raising of a weight of 1,000 pounds through a height of 10 feet involves a certain amount of work; the raising of 500 pounds to a height of 20 feet, or 10 pounds to the height of 1,000 feet involves the same amount of work. The work performed in raising 1 pound 1 foot is called a foot-pound.

ENERGY. Energy is a term used to denote capacity for doing work. It may be either active or potential.

A body of water behind a dam possesses potential energy. Water moving a wheel, in its descent to a lower level, is a good example of active energy.

POWER. The power of an engine is the energy it can exert in a definite interval of time. It takes a certain amount of power to raise 1,000 pounds through a height of 10 feet, in one minute of time. It would take twice as much power to raise the same weight twice as high, in the same time—or the same weight, in half the time.

EFFICIENCY. There is a difference between the power exerted by an engine and the power that is transmitted from the engine to a distant machine doing useful work. The difference between the two is that part of the original power that is used up in friction and other resistance, in the engine itself and in the transmitting machinery. The ratio of the amount of power delivered to the working part, as compared with that of the steam moving the piston, is called the efficiency of the machinery. It may be 90 per cent of the original power, more or less, according to the degree of perfection of the machinery.

HORSE-POWER KILOWATTS. The power, or capacity, of an engine is usually expressed in horse-power or in kilowatts. A horse-power is the amount of power required to raise 33,000 pounds 1 foot high in one minute of time.

This measure of power was fixed upon by Watt when he found it necessary to express the performance of his engines in terms commonly understood. It was supposed to be equal to the amount of power that

a strong horse could exert in the same time. Few horses could, however, continue such a performance for any length of time. The term kilowatt denotes a certain quantity of electricity generated in a minute of time. It is the common measure of electric generators and is coming to be used as a measure of power generally. Seven hundred and forty-six watts equal one horse-power; a kilowatt, or 1,000 watts, is therefore equivalent to about 1⅓ horse-power.

The power of an engine, as measured in the cylinder, is called the indicated power; the power delivered at the circumference of the driving-pulley is usually called the brake-power and is always something less than the indicated power because of the resistance that has to be overcome in the engine itself—as has been already explained.

Calculating Horse-Power. If we have a piston, of a certain number of square inches, moved by an even pressure of steam through a certain number of feet per minute, we can easily figure out the horse-power of the engine. For example, let us suppose that the pressure of steam, as indicated by the gauge, is 150 pounds per square inch; that the piston has an area of 50 square inches; that the length of the stroke is 1 foot, and the number of revolutions 120 per minute, then we will have 50 times 150 pounds or 7,500 pounds moved 240 feet per minute or 1,800,000 foot-pounds per minute.

Knowing that 33,000 foot-pounds per minute equal 1 horse-power, we have, now, only to divide 1,800,000 by 33,000 and we get 54$^{18}/_{33}$ as the horse-power of the engine. If we let P stand for the pressure, A for the

area of the piston, L for the length of the stroke and N for the number of strokes per minute, we have the formula,

$$\text{H.P. (horse-power)} = \frac{P \times A \times L \times N}{33{,}000}.$$

Now, it makes no difference how the four quantities that are to be multiplied together are arranged, so we may transpose the A and L, and we have

$$\frac{P \times L \times A \times N}{33{,}000}, \text{ or H.P.} = \frac{PLAN}{33{,}000}.$$

This is an easy formula, or rule, to remember—the letters of the word *PLAN* multiplied together and divided by 33,000.

The size of the piston is usually given in terms of its diameter. In order to find the area of a circle whose diameter is known, the square of the diameter should be multiplied by .7854. To find the number of square inches, then, in a piston 8 inches in diameter, we should multiply 8 by 8 and the product by .7854. The result will be 50.2656, a little more than 50¼ inches.

The length of the stroke, too, is often given in inches; but in order to use our formula, it must be reduced to feet. If the stroke is 14 inches it must be put down as 1⅙ feet. It must not be forgotten, too, that the length of the stroke is twice the length of the crank and that there are twice as many strokes as revolutions per minute.

Suppose, then, we wish to find the horse-power of an engine, with a piston diameter of 8 inches and a crank

length of 7 inches, making 100 revolutions per minute, under steam pressure of 150 pounds per square inch. We have

$$\text{H.P.} = \frac{P\,L\,A\,N}{33{,}000} = \frac{150 \times 1\tfrac{1}{6} \times 50\tfrac{1}{4} \times 200}{33{,}000} = 53\tfrac{13}{44}.$$

This, it should be understood, is only a rough method that is liable to error, because it does not take into account the variations of pressure in the cylinder. It is here assumed that the boiler pressure prevails in the cylinder, and that it is uniform during the whole stroke. These conditions seldom, if ever, occur. There is always some loss of pressure whenever steam is conducted through pipes from a boiler to an engine several feet away, and the pressure is almost always less at the end of the stroke than at the beginning—due to the cut-off.

If we could have a number of steam-gauges attached to the cylinder along its length, only an inch or so apart, and could read them as the piston passes along we could find the mean effective pressure by adding the readings all together and dividing by the number of the gauges; this, in effect, is what we are able to accomplish by the use of an "indicator."

The Indicator. Fig. 116, shows two views of the principal features of a steam-engine indicator, for reciprocating engines.

It consists of a small steam-cylinder, about an inch in diameter, fitted with a piston which is held in place near the bottom of the cylinder by means of a spring, shown at the left. Attached to the piston-rod is a horizontal lever moving about a fulcrum, attached to the side of the cylinder and carrying a pencil at the

other end. A little to the right is shown another somewhat larger cylinder which turns on a vertical axis. This cylinder is kept from turning, when not in use, by

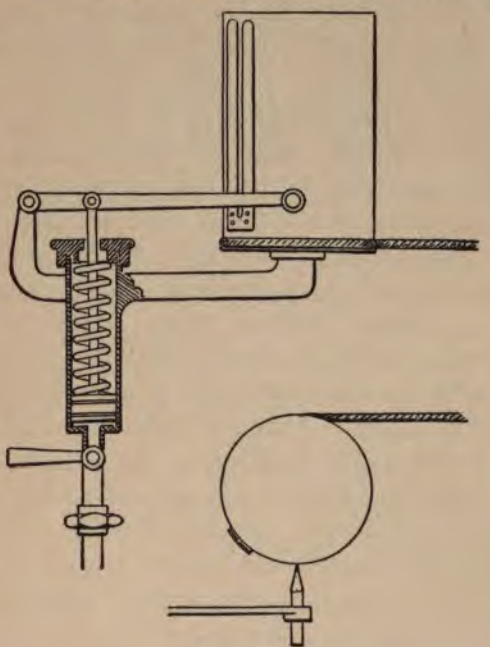

FIG. 116

means of a light spring on the inside which also serves to bring the cylinder back to its original position after it has been turned about its axis. Attached to the bottom of this cylinder, and wound partly around it, is a cord the other end of which is attached, when in use, to the cross-head of the engine or to some other piece actuated by the cross-head. There is also a device for holding a small sheet of paper on the cylinder so that it cannot

slip while the instrument is in use. The pencil is adjusted so that the point rests on the paper.

The small cylinder, first described, is attached to one end of the engine cylinder by means of a small pipe and union joint provided for the purpose. A steam-cock, attached to the indicator, makes it possible to admit steam or to shut it off as desired.

After the indicator is attached to the engine cylinder, the cord is fastened to the cross-head connection in such a way that the cylinder carrying the paper is made to move through nearly a whole revolution at every stroke of the engine. The pull on the cord moves the cylinder in one direction and the spring pulls it back during the return stroke. Before steam is admitted to the indicator, it is plain that the pencil-point will trace and retrace a horizontal line near the bottom of the sheet of paper as the holder is rotated back and forth. Now, let steam be admitted below the small piston of the indicator; the spring will be compressed and the pencil-point will be raised much or little according as the pressure varies in the engine cylinder. If the engine has a common slide-valve cutting off at about three-quarter stroke, the diagram traced by the pencil-point will be something like that shown in Fig. 117. At first the steam pressure will move the pencil quickly upward, and the left-hand vertical line of the diagram will be traced.

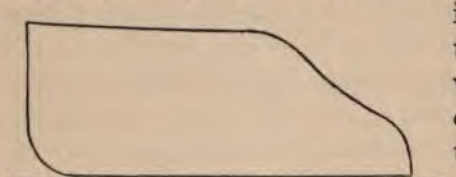

Fig. 117

At the beginning of the stroke the cross-head has no motion either to the right or left, so only a vertical line will be traced. There is always greater pressure in the cylinder at the beginning of the stroke than at any other point, due to pre-admission and compression, so the pencil-point will immediately begin to fall a little, as the piston of the engine moves to the right and the sheet of paper is made to move with it by means of the cross-head and cord connection. As the engine piston continues to move toward the right, the pencil traces the top line of the diagram.

The line is nearly horizontal until the point of cut-off is reached, but it generally has a slightly downward slope due to a slight loss of pressure as the steam from the boiler is retarded in passing through the ports, and from other causes. The spring over the indicator piston immediately presses the piston back a little, whenever the pressure from below grows less.

When the point of cut-off is reached and steam is no longer admitted from the boiler, the indicator piston begins to fall rapidly and the pencil-point traces a parabolic curve which is continued as long as the steam is used expansively. When the exhaust-port is opened, there is a rapid fall of pressure, indicated by the almost vertical drop of the extreme right-hand end of the diagram.

The cross-head now begins to move back toward the left and the pencil traces a horizontal line indicating no pressure until the piston reaches a point near the left limit of its stroke. This indicates the point where the exhaust-port is closed, and steam is beginning to be ad-

mitted for the next right-hand stroke. In describing the action of the slide-valve engine, it will be recalled, mention was made of the necessity for opening the steam-port slightly before the beginning of the stroke. This is accomplished by giving "lead" to the valve. Indicator diagrams show plainly where the pre-admission occurs by the sudden upward turn of the line that is being traced by the indicator pencil as the exhaust line of the diagram. The piston and cross-head continue to move to the left, and this tends to compress the steam that is being admitted together with any exhaust-steam that may still remain in the cylinder after the exhaust passage is closed.

If there is too much pre-admission and compression, the pencil will indicate it by a high point at the upper left-hand corner of the diagram.

Thus we see how a properly adjusted indicator can be made to show just how the steam is behaving in the cylinder. By applying the indicator to the opposite end of the cylinder, a diagram of the opposite stroke can be obtained. This provides an easy way of finding out whether the slide-valve is properly set; for the diagrams of the two ends should correspond in shape. If there is a difference in the cut-off, or more lead at one end of the cylinder than at the other, the indicator diagram will clearly show the discrepancy. Indicator diagrams are used to determine the mean effective pressure that has been exerted by the steam during the stroke. The horizontal lines of the diagram bear a certain relation to the stroke and the vertical lines to the pressure in the cylinder. By using proper scales of measurement, the area of the diagram may be taken as

a measure of the energy expended by the steam in moving the piston. The greater the area of the diagram, the greater the energy expended; but a diagram of large area does not always indicate economy in the use of steam. On the contrary, if the diagram is nearly rectangular, and of the largest possible area, it indicates that steam at boiler pressure has been admitted through practically the whole stroke, and that waste of steam has occurred because of failure to employ its full expansive force. An indication that steam had been used economically would be an early cut-off and a smooth parabolic line running to a low point before the exhaust occurs.

Again, the rounded left-lower corner, due to pre-admission and compression, does not necessarily indicate a poor diagram, for, notwithstanding the fact that it subtracts from the area of the diagram, it shows necessary back-pressure, that must be exerted in order to bring the piston and other moving parts to rest before the next stroke begins. Springs of various degrees of tension are used for high and low pressures, and the indicator sheets are ruled to correspond, so that the height of any portion of the indicator outline above the horizontal line of no pressure, made before steam is admitted to the indicator, indicates the pressure in the engine cylinder at that particular moment of the stroke. The bottom line, corresponding to the next, or backward stroke of the en-

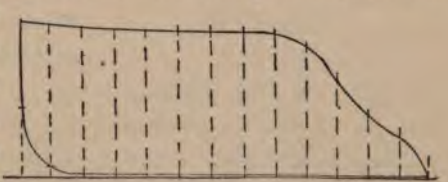

FIG. 118

gine, indicates back-pressure. This back-pressure must be subtracted in getting the mean effective pressure. By dividing the diagram into sections by means of vertical lines, as indicated in Fig. 118, and putting down to proper scale the pressures, less back-pressure, indicated by the distance between the two points where the top and bottom lines of the diagram cross the vertical lines, then adding these all together and dividing by the number of vertical lines, a very close approximation to the real mean effective pressure of the entire stroke can be obtained.

In applying the formula

$$\text{H.P.} = \frac{P\,L\,A\,N}{33{,}000},$$

this mean effective pressure should be used as the value of P, rather than the boiler pressure.

Fig. 119 shows the kind of diagram that is obtained from a Corliss engine, cutting off early in the stroke and moving rather slowly. Fig. 120 shows a diagram from a quick-running engine where it is necessary to use high compression in order to bring the rapidly moving piston and its connections quickly to rest before the beginning of the next stroke. An indicator, such as has been described, cannot, of course, be used on a turbine engine.

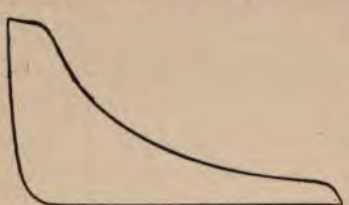

FIG. 119

BRAKE HORSE-POWER. It has already been stated that there is a considerable loss of power between the

piston of a reciprocating engine and the rim of the driving pulley. The power delivered at the working end of the engine is, of course, of greater concern to a manufacturer than that generated in the cylinder, for it is the only part there can be made use of. But the indicated power is developed by burning fuel, and it is important to know that no more of this power is being absorbed in driving the engine itself than is absolutely necessary. In other words, the efficiency of the engine is of great importance and it can only be determined by dividing the brake horse-power by the indicated horse-power. Both for the purpose of determining the efficiency of the engine and the amount of useful work it is capable of performing, the brake horse-power of every engine should be known.

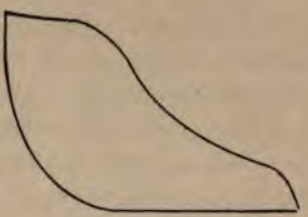

FIG. 120

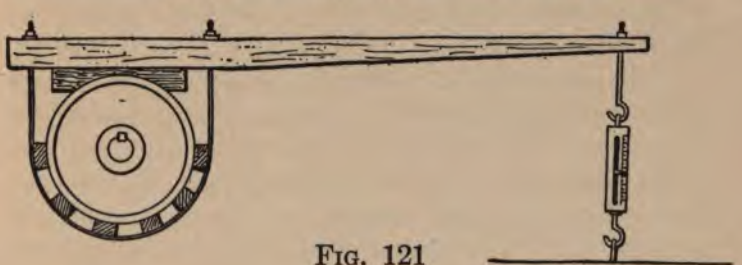

FIG. 121

Fig. 121 shows the construction of a common device for measuring brake horse-power. It consists of a lever, usually of wood, attached at one end to a fric-

tion brake and at the other to a spring balance. The brake is usually made of a series of blocks of wood held in place against the rim of the driving pulley by means of rods or chains fastened to the lever, as shown in Fig. 121. Between the top of the pulley and the lever-arm there is a block of wood fitted to the shape of the pulley and fastened to the lever-arm. By turning the nuts at the ends of the rods the brake may be tightened as required. The spring balance at the other end is attached to a solid foundation.

The brake should be adjusted so that the engine at full power can turn the driving pulley at working speed.

The spring balance will then indicate the amount of pull at the end of the lever-arm. That is to say, we have the amount of resistance to turning that exists at that point; but the resistance at the surface of the driving pulley is as many times greater than that measured by the spring balance as the distance from the centre of the shaft to the point where the spring balance is attached is greater than the half diameter of the driving pulley.

If the former be eight times the latter, the resistance at the surface of the driving pulley will be eight times that registered by the spring balance.

The rim speed of the driving pulley, in feet per minute, may be easily calculated from the number of revolutions of the engine, and thus the work being done, in foot-pounds, can be ascertained. The number of foot-pounds per minute divided by 33,000 gives the brake horse-power.

If it is desired to know the efficiency of the engine it

may be found by dividing the brake horse-power by the indicated horse-power.

In testing brake horse-power, by means of such a device as that shown in Fig 121, it is well to take a considerable number of readings—spring balance readings and number of revolutions per minute—and to take the average of all the readings for the final result. No account has here been taken of the amount of energy converted into heat by the friction of the blocks on the rim. More accurate tests can be taken by more complicated apparatus, where there is provision for absorbing the heat, due to friction, by water. The number of degrees that a given quantity of water is raised in temperature, in a given time, may be taken as a measure of the energy that has been converted into heat. This should be added to the energy that is doing work at the surface of the driving pulley in order to determine the full amount of energy developed at that point.

The effective power of electric-light engines is easily measured by the number of kilowatts of electricity generated. Engines designed for other purposes are often temporarily connected up with lighting systems, for the purpose of measuring their working power. Inasmuch as 746 watts correspond to 1 horse-power, it is an easy matter to calculate horse-power from watts or kilowatts.

CHAPTER VIII

GAS-ENGINES

THE great disadvantage of the steam-engine, as a means of converting the heat of steam into mechanical energy, lies in the fact that the real source of energy, namely, the combustion of fuel under the boiler, is so far away from the point of application. The heat generated by combustion is only partially conveyed to the steam, and some loss always occurs in conducting steam from the boiler to the engine. If it were not for the fact that comparatively inferior grades of fuel can thus be made to yield energy, this method would have little to recommend it, as compared with that employed through the use of internal-combustion engines, where the heat of combustion is directly utilized in the creation of energy. The explosion of gas in the cylinder of a gas-engine is just as truly the combustion of fuel as the burning of coal under a steam-boiler. Highly concentrated fuel, in the form of gas, is mixed with air and fired through a succession of explosions, instead of by the slow combustion of coal in an ordinary furnace.

Fig. 122 shows, diagrammatically, one of the simplest forms of an internal-combustion engine, where the fuel is ordinary city gas and no electrical device for firing is employed. A cylinder, usually of cast iron, is connected at one end with a combustion-chamber and

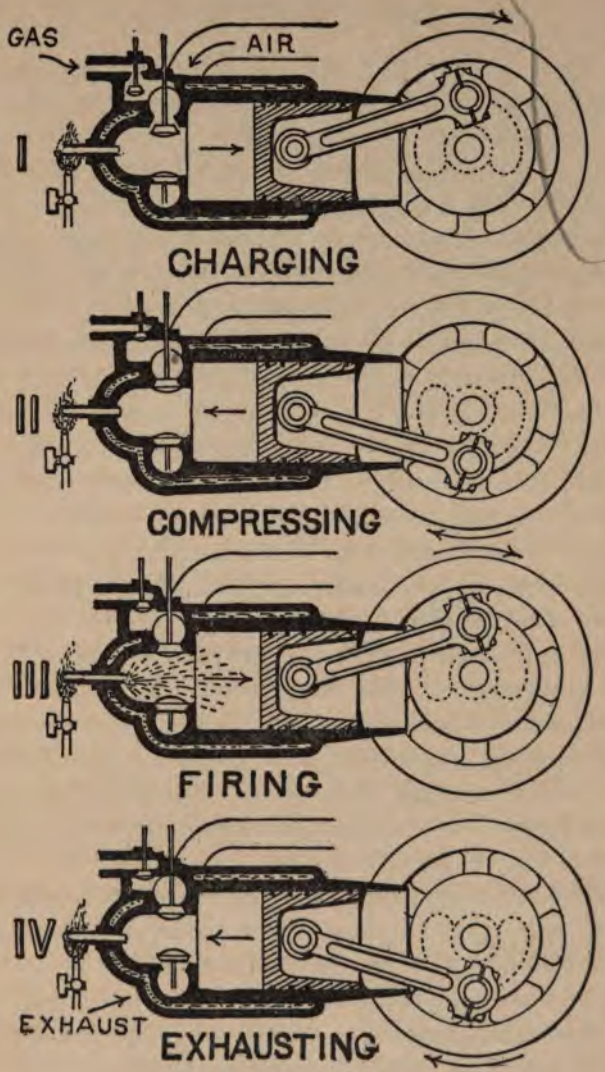
GAS
AIR
I
CHARGING
II
COMPRESSING
III
FIRING
IV
EXHAUST
EXHAUSTING

FIG. 122

open at the other. The cylinder and combustion-chamber are surrounded by a water-jacket, the necessity for which will be later explained. The combustion-chamber is supplied with a system of valves which are usually operated by cams driven by the engine itself. One of these valves controls the supply of gas, another admits a mixture of gas and air to the cylinder, and the third controls the exhaust. A single-acting piston, of the trunk variety, operates a crank through the medium of a direct-acting connecting-rod. The crank is usually supplied with a counter-weight, and a heavy fly-wheel of small diameter is an important feature. The cylinder and piston are, of course, carefully machined and fitted, and several cast-iron piston-rings are used to make a gas-tight joint between them.

The method of operation is quite different from that of the steam-engine.

The type now under consideration is known as the four-cycle engine. The number, four, refers to the separate events that take place during a single cycle. That is to say, the drawing in of the charge, its compression, its firing, and the exhaust complete the cycle which requires four strokes of the piston, or two revolutions of the engine.

The top figure shows the piston moving toward the right, with the gas and air valves open and the exhaust-valve closed. This stroke of the engine, which in the case of one cylinder depends entirely on the inertia of the fly-wheel, draws in a charge made up of a mixture of gas and air controlled by the gas and air valves.

When the piston reaches the outer limit of its stroke,

the gas and air valves suddenly close and the inertia of the fly-wheel continues its work by forcing the piston back, as shown in the second figure from the top. When the piston has been moved to the limit of its stroke in this direction, the whole charge will be compressed into the combustion-chamber directly over the valves. This charge, which consists of a mixture of gas and air in the right proportions for rapid combustion, is heated by compression but not sufficiently to cause ignition. Attached to the combustion-chamber, in this simplest of all forms of the gas-engine, is a small tube, closed at the outer end. Under the closed end of this tube a gas-jet is kept burning, which makes the tube quite hot. A portion of the compressed charge is forced into the tube, and the heat causes the mixture to explode. This explosion, which is nothing more nor less than the rapid combustion of gas in the air that is mixed with it, generates a large amount of heat, which immediately becomes available for power, as it expands the products of combustion and forces the piston to the right, as shown in the third figure from the top. This is the working stroke, which not only moves the machinery, with which the engine is connected, but stores up enough energy in the fly-wheel to carry the piston back and forth three times, in preparation for the next working stroke.

When the piston reaches the outer limit of the working stroke, the exhaust-valve opens, as shown in the bottom figure of the diagram. The gases that have been moving the piston now suddenly rush out through the exhaust, and the piston, through the action of the

fly-wheel, follows up the escaping gases and comes into the position required for the charging stroke. We have now traced the movements through an entire cycle and the general principle of action should be clear.

It must, of course, be understood that the diagrams illustrate only the main principle of action, and that actual working machines are more finished in detail. In the first place, the valves and the mechanism which actuates them must be so carefully proportioned and adjusted that the right quantities of gas and air shall be admitted to the cylinder during the charging stroke. Again, these valves must close at the proper instant and fit so perfectly that none of the charge or "mixture" may leak through during the compression stroke.

Where an ignition tube is used, the gas flame must be so adjusted that the tube will be heated to the right temperature to ignite the charge at the right instant, namely, when the piston has nearly reached the limit of the compression stroke. It is customary to use some sort of protection to the flame, so as to insure contact between the flame and the tube under all conditions; and the flame itself is carefully adjusted by means of a regulating gas cock. In modern practice, magnetos, timers, and spark-plugs are nearly always substituted for the ignition-tube.

Long trunk pistons, like that shown in the diagram, afford ample room for a number of piston rings, which are usually of the simple cast-iron spring variety. Small engines are commonly equipped with two or three sets only, but large gas and gasoline-engines

sometimes have eight or more of these rings. It must be evident that any gas that leaks past the valves or piston rings is entirely wasted.

Conical valves, like those shown in the diagram, are generally used because they are less affected by heat than most other kinds. That is to say, a slight degree of unequal expansion between a conical valve and its seat does not materially affect the fit of the valve. Moreover, conical valves can be easily removed for inspection and be ground to their seats when they become worn.

The pressure exerted by an exploding charge, of gas and air, often runs as high as three hundred or even five hundred pounds to the square inch. Strong cylinders and moving parts are, therefore, necessary to avoid fracture and serious accidents. Pistons, connecting-rods, and cranks are usually much stouter than those used in connection with steam-engines, in order that the shocks of the explosions may be transmitted to the driving-shaft without damage. The pressure rapidly falls after the piston begins to move forward on its working stroke, so the cylinder does not need to be extremely heavy except near the head. Here, too, the flanges and piston head serve to reinforce the cylinder at the point where the greatest strength is required.

The combustion-chamber needs to be very strong because it must withstand the full shock of the explosion, but here, again, the small diameter makes it unnecessary to use great thicknesses of metal. Oftentimes a separate "liner" is used to take the shock of the

explosion and the wear of the piston. Whenever this is done the liner is made thicker, and protected by outside flanges, at the explosion end.

Another important adjunct is the water-jacket. The temperature of an exploding charge is very high—almost equal to that necessary to melt iron—so it is necessary to provide some means of conducting away this excessive heat to prevent the destruction of the engine. Water, circulating between the inner and outer shells of the cylinder and combustion-chamber, is commonly used for cooling purposes.

A centrifugal pump is generally used to keep this cooling water in constant circulation through water-jacket, piping, and radiator. The radiator is usually made of thin pieces of sheet metal brazed together in such a way as to form a cellular structure with a large amount of surface compared with its cubical capacity. In this way the cooling water is exposed to the air and gives up a large portion of its heat before it is again circulated through the water-jacket. A fan is generally used to keep a current of air constantly passing over the radiator to facilitate the cooling process.

The water-jacket does not need to cover the extreme outer end of the cylinder, for the hot gases never come in contact with that end because of the long piston. The outer end of the cylinder serves as a guide and is generally just long enough to cover the piston when in its extreme position. Lubrication of the piston, and other moving parts, is very important. Oil that would be suitable for lubricating steam-engine pistons cannot be used because of the excessive heat. There

are, however, certain kinds of mineral oil, derived from petroleum, that will withstand the high temperature of internal-combustion engines and at the same time furnish proper lubrication.

It may seem, on first thought, that the power used on the compression stroke is wasted, but a little consideration will make it clear that this is not altogether so. The heat that is generated by compression is utilized, in part at least, in giving added energy to the working stroke; and the concentrated charge is much more powerful than a mixture of gas and air at atmospheric pressure would be, so there is a real gain when we take into consideration the entire cycle.

One objection to the ordinary gas-engine, in former years, was that it could only be used in localities where city gas was available.

In recent years, however, it has become quite common to install small gas plants for the sole purpose of furnishing gas for gas-engines. These plants are called "producers" and they usually occupy less space than ordinary steam-boilers of like capacity.

THE GAS-PRODUCER. A gas-producer is a rather simple device. Its essential parts are few and not very complicated.

If a large bed of coal is placed on a fire at one time, blue flames will not infrequently be seen playing over the surface of the partially heated, but still black, coals of the upper layer. This is burning carbon monoxide which has been formed by the passage of the first products of combustion through the mass of coal that overlay the hottest part of the fire.

When coal is burned with an ample supply of air, as it is in an ordinary grate over an ash pit, carbon dioxide is formed. That is to say, one molecule of carbon unites with two of oxygen.

As this gas rises through the hot coal, to make its escape up the smoke-stack or chimney, it takes up another molecule of carbon; and we have two molecules of carbon for every two molecules of oxygen—or one-to-one instead of one-to-two, as originally. When this new gas arrives at the surface, where there is a better supply of air, it takes up another molecule of oxygen which again produces the original dioxide. This latter process is what we observe when we notice the blue flame on top of the coal. If we were burning coal under a boiler, the extra heat, produced by the burning of this monoxide, would add materially to the heating effect, and would be desirable. If, however, air is kept from circulating, over the surface, of the bed of coals and this gas is gathered into a tank, it will serve as a fine gas-fuel supply. This is the principle of the gas-producer: the production of monoxide from dioxide and its collection above the fire for use as a gaseous fuel.

Of course there is a large amount of nitrogen—four-fifths of the entire weight of the air admitted under the fire—which also rises through the fuel but is unchanged by the passage. This nitrogen finally becomes mixed with the monoxide and the two pass off together as "producer gas." Various impurities are afterward extracted by a "scrubber" which is situated between the producer and the storage tank, or gas-engine.

After it has passed through the producer and scrubber, the gas is ready for use as a gas-engine fuel.

In the early eighties of the last century, producer gas, made by this simple process, was first used to drive gas-engines, and it was found that a given amount of coal would produce quite satisfactory results, when used in this way. A few years later, it was found that a much improved gas, for such purposes, could be made by blowing a certain amount of steam through the fuel while the carbon monoxide was being generated. "Water-gas" was thus formed which mixed with the ordinary producer gas and added greatly to its quality for use in internal-combustion engines.

In the older forms, the producers *forced* the gas into the engine, so to speak, and much gas was often wasted. In modern installations the engine *sucks* gas from the producer, and only uses what is necessary for its operation.

Fig. 123 is a sectional view of a modern suction-producer, using anthracite coal.

The producer proper is shown at *A*. It consists of a steel drum, lined with fire-bricks, having a hopper at the top through which the fuel is fed, and a peculiar grate at the bottom through which the air flow is easily regulated.

Near the top of the producer is a short pipe leading into the top of the vaporizer, *B*. The vaporizer is an improved apparatus for adding steam, or water-gas, to the flow before the combined gases reach the scrubber, *C*. The vaporizer contains two or more vertical iron pipes with ribs or flanges cast on the outside, to increase the heating surface. These pipes are connected at the top with a small water-supply, and one of the pipes is open at the bottom for the escape of

the water-gas. The vaporizing pipes are contained in a vertical drum, having a funnel-shaped bottom, which opens downward into a pool of water which forms a seal. Near the bottom of the funnel is a branch pipe

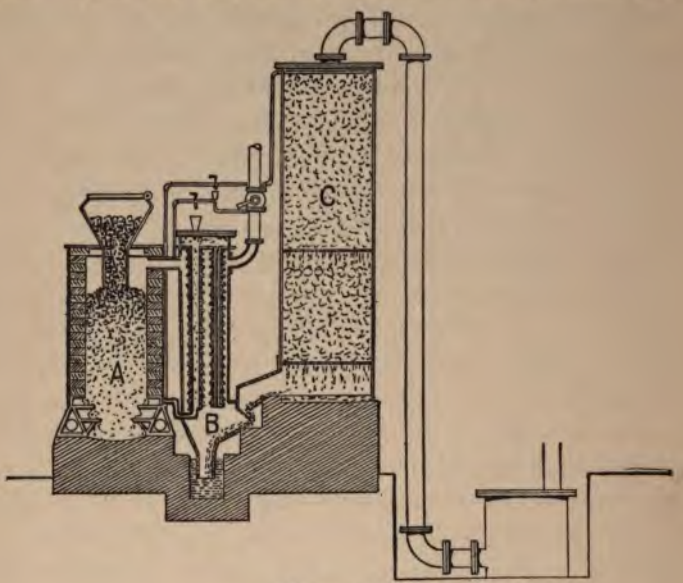

FIG. 123

which connects with the bottom of the scrubber, *C*. The scrubber is merely a tall steel cylinder with two or more perforated bottoms, which support quantities of coke at different levels. The bottom of the scrubber is higher than the bottom of the vaporizer, so that it will readily drain into it. The scrubber is a very necessary part of the apparatus, as it collects the dust that escapes from the producer, with the gas, and prevents

it from getting into the engine. To the top of the scrubber is attached a large pipe for conducting the gas to a receiver, from which the engine draws its supply.

At the top of the scrubber is a water-sprayer, from which water is constantly dripping into the coke. The water percolates downward and reaches the first perforated bottom. It drops through this into the second body of coke and finally reaches the last perforated bottom and falls into a shallow pool, at the bottom of the scrubber which overflows into the pool at the bottom of the vaporizer, as indicated.

The reason for using different layers of coke in the scrubber is to make it easy to remove foul coke without it being necessary to remove all the coke in the scrubber.

The lower layer, of course, needs to be renewed oftener than the upper one, because it takes the dust from the gas as it first issues from the producer. In falling from the bottom of the scrubber to the lower level, the water which has passed through the scrubber meets "baffle-plates" and forms a thin sheet through which the gas must pass as it goes from the bottom of the vaporizer to the bottom of the scrubber.

The slowly burning coal, at the bottom of the producer, is supplied with the right amount of air for the formation of dioxide—the usual product of burning coal. This dioxide, together with the released nitrogen of the air, must ascend through the heated mass of coal above, where it takes up more carbon and becomes monoxide—as has been previously explained. This heated gas escapes, through the short pipe at the top, into the top of the vaporizer drum. Here it serves to heat the water

contained in the vertical corrugated pipes. It then passes downward, where it is mixed with the water-gas, at *B*, and passes through the water-spray into the bottom of the scrubber. It next ascends through the body of coke, where it is purified of dust, and then passes into the large supply pipe. A partial vacuum maintained in the receiver, at the right, produces a constant suction, and keeps the gas moving through the vaporizer and scrubber as fast as it is produced.

This apparatus is much safer than the older pressure apparatus, for the suction tends to draw inward any gas that might otherwise escape from a leaky joint. Carbon monoxide is a very dangerous gas to inhale, for, while poisonous, it has no odor by which it can be detected and victims are often overcome before they are aware of their danger.

The producer just described is arranged for the use of anthracite coal only. Soft-coal producers are more complicated than that just described, for provision has to be made for extracting tar, which all soft coals contain. This tar would gum up the engine and seriously interfere with its operation if allowed to pass over with the gas. Soft coal is so much more abundant, and so much cheaper, than anthracite that it is used in producers wherever possible. The tar, coke, and other by-products of the producer, are of course, valuable, and when sold their value should be subtracted from the original price of the fuel.

It is, indeed, surprising how small a quantity of coal is needed to keep up a supply of gas for an efficient gas-engine.

GAS-ENGINE GOVERNOR. There are many different devices for regulating the admission of gas and air to the combustion-chamber of gas-engines and governing the speed of the engine under variations of load. Fig. 124 shows a gas-engine governor that acts directly on

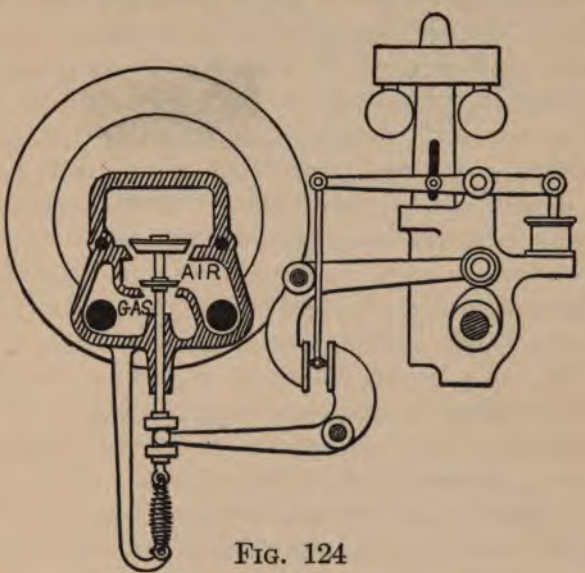

FIG. 124

the gas and air admission-valves, which in this case are mounted on a single stem.

Instead of using eccentrics, gas-engine admission-valves and governors are usually driven by means of cams on shafts geared to the main shaft and running parallel to the axis of the cylinder. An end view of such a shaft is shown in Fig. 124, near the right. This shaft carries a cam which operates the long arm of a

bent lever. Below the short arm of this lever, and actuated by it, is another, of similar shape, turned in the opposite direction. The long arm of the latter operates the valve-stem, which is ordinarily held down by means of a coil spring. The lower valve admits gas, which mixes with air just below the main induction-valve. This valve opens directly into a combustion-chamber attached to the cylinder of the gas-engine. It will readily be seen that the cam raises the long arm of the lever, first described, and that the short arm of this lever presses on a small piece of steel which in turn presses against the short arm of the lower lever, so as to raise the long arm and the valve-stem with which it is connected.

If the piece of steel were neither raised nor lowered the valves would be raised the same distance each time the cam came around, which, by the way, is only once for every two revolutions of the engine.

But the charge should vary with the load on the engine, and this variation is accomplished by the action of an ingeniously constructed governor, mounted over the cam-shaft. As the speed increases, due to a light load, the balls move outward, and this raises a horizontal lever-arm pivoted to the base of the governor standard. Attached to this lever-arm is a light rod, the lower end of which supports the small piece of steel between the levers that operate the valves. The short arm of the governor lever is connected with a small dash-pot, to prevent a too sudden movement of the lever.

As the balls of the governor move outward and the

lever is raised, the small piece of steel is also raised between the smooth flat surfaces of the valve lever-arms. As the piece of steel is raised the effect is to shorten the arm of the upper lever and to lengthen the arm of the lower lever. A little consideration will make it clear that this will shorten the movement of the long arm of the lower lever and allow a smaller opening of the valves.

In case the speed of the engine, under a heavy load, drops too low and the governor valves fall, the piece of steel will be lowered and the valves will be opened wider and a heavier charge will be admitted.

Thus a regular motion derived from the action of a cam may be varied by a governor to meet the demands of a heavy or light load on the engine. This is only one of many ingenious devices for regulating the speed of gas-engines.

Small engines are usually equipped with a very simple "hit-or-miss" device which is actuated by a governor in such a way that no charge is admitted when the speed exceeds a certain number of revolutions. The fly-wheel is depended upon to keep up the motion until the next charging stroke comes around, when the speed will generally be reduced sufficiently to allow the governor to act in such a way as to allow the induction-valve to open.

This is, of course, an imperfect method of governing the speed of a gas-engine, and is not well adapted to situations where smooth running and slight variations of speed are important considerations.

One objection to gas-engines is the difficulty of start-

ing them. We have seen that the reciprocating steam-engine has two dead centres, from which it cannot be started by direct steam pressure, but this difficulty is overcome by using care in not allowing single-cylinder engines to come to rest on an exact dead centre, or by placing the cranks at right angles to each other where two cylinders are used—as in the case of the locomotive.

The gas-engine is not only subject to the same objections as the steam-engine with regard to dead centres, but, with single-acting cylinders and only one working stroke in four, it is far more difficult to have all conditions right for easy starting than in the case of the steam-engine.

Starting Devices. Heavy fly-wheels are almost always necessary. In the case of a small engine the fly-wheel may often be turned by hand through a suction and a compression stroke when the sparking device ignites the charge and the engine starts by its own power. This is not so easily done, however, in the case of a large engine, and other means have to be employed.

Sometimes mortises are cast in the rim of the fly-wheel in which a steel bar can be worked to move the crank past a dead centre; in other cases, a hand wheel is made to operate a pinion that works in gearing on the under side of the fly-wheel rim. The pinion is, of course, arranged so as to be easily thrown out of gear when the engine is once started. A tank of compressed air is usually provided for starting the pistons of large gas-engines. When the heavy fly-wheel has once been set

in motion with sufficient speed to carry the piston through a compression stroke, the compressed air is suddenly shut off and an explosive mixture is drawn in instead. The next stroke being a working stroke, the engine will usually begin immediately to "pick up" under its own power.

Gas-engines, like steam-engines, are often built with more than one cylinder; sometimes they are equipped with double-acting cylinders, but even then they are more difficult to start than steam-engines, because every stroke is not a working stroke.

So far we have considered only the four-cycle type, but gas-engines are sometimes constructed to operate on what is called the "two-cycle" principle.

As we have seen, the four events of the four-cycle type are: charging, compressing, firing, and exhausting. In the two-cycle type the events are consolidated, so to speak. The charge is admitted under pressure during the latter part of the exhaust stroke, and this is followed immediately by a working stroke.

While there is an advantage in having twice as many working strokes as in the four-cycle type, there is this disadvantage: the explosive mixture of gas and air is apt to be contaminated by mixture with the burned gases of the exhaust, and less energy is developed than where a purer mixture is used. "Baffles" are used to prevent the mixture of the entering charge with the exhaust, but they are never wholly effective. Two-cycle engines are less sure in their action—because of impurities becoming mixed with the charge—than the four-cycle type, but they are lighter and more simple,

and therefore cheaper. Two-cycle engines are often arranged so that the induction and exhaust ports are opened and closed by the action of the piston alone; in such a case no valve-gear is necessary.

The two-cycle engine will be more fully explained in the next chapter.

CHAPTER IX

GASOLINE-ENGINES

No invention of modern times has been more generally and successfully applied than the gasoline-engine. Steam-engines have filled the need where very powerful prime movers were required—particularly in situations where bulky fuel, like coal, could be readily obtained; gas-engines have come to be used extensively where the lighter fuel is available or conditions favor its manufacture on the spot; but gasoline-engines are in use, not only in busy centres and alongside of other motors, but in out-of-the-way places, on farms, on the water, and anywhere that the convenient fuel, gasoline, can be found; and where in this wide world can one go that the Standard Oil Company, or some other dealer in this useful commodity, has not placed its product on sale!

Wherever a small amount of power is needed, in situations where coal is scarce or not easily transported and where considerable investments in power-plants do not seem advisable, the gasoline-engine is supplying to-day a wide demand.

The farmer is fast substituting gasoline for animal power in the multiform work of the field, the dairy, and the farmstead. Every busy waterway is alive with small craft propelled by this convenient power; and, not only are city streets and many country roads

crowded with gasoline-driven automobiles, but even the air is becoming more and more alive with the hum of the airplane motor.

Who would have believed a few years ago that we would be witnessing to-day engines of over four hundred horse-power propelling themselves through the air with no other support but that which the atmosphere itself offers to rapidly moving bodies!

Twelve-cylinder Liberty Motors weighing eight hundred and fifty pounds were in use at the close of the great World War, capable of carrying much more than their own weight through the air at the rate of about two miles per minute.

The secret of the almost universal application of the gasoline-engine lies in the fact that it uses an extremely concentrated and comparatively inexpensive fuel with remarkable efficiency and little waste. By means of internal combustion the fuel is used exactly where it is needed to produce immediate results. Comparatively little attention is required to keep a gasoline-engine supplied with fuel, and almost any person can learn to run one.

After all, however, the modern gasoline-engine is not a simple machine, and not every person who is able to keep one running under favorable conditions can tell exactly what is the matter when something goes wrong. The gasoline-engine has reached a high stage of perfection, but the progress of its development has been gradual. It is only as the result of much study and experimentation that we have such a useful and easily controlled source of power. It has many

forms and is usually accompanied by various accessories, but its vital and essential parts have now assumed something like standard forms.

Its principle of action is the same as that of the gas-engine, already explained. It is, in fact, a gas-engine, but one in which the gas is neither supplied by city mains nor by "producers," but generated within the engine itself—that is to say, in a carburetor attached to the engine between the gasoline tank and the cylinder. The carburetor is one of the most vital parts of a gasoline-engine, and its construction will be taken up later in this chapter.

The cylinders and pistons of gasoline-engines do not differ essentially from those already described under gas-engines.

They are almost always single-acting, heavy and strong at the closed end, where the explosion occurs, and surrounded by a water-jacket for the purpose of preventing overheating.

While in gas-engines, such as we have been studying, combustion-chambers of considerable size are desirable and necessary, in gasoline-engines small combustion-chambers are considered better than large ones, as it is desirable to have the charge concentrated as much as possible and the point of ignition very close to the piston.

Like the gas-engine, the gasoline-engine derives its energy from the ignition of a combustible gas mixed with air, which has previously been compressed into a small space above the piston. The process of getting the combustible charge into the cylinder of a four-

cycle gasoline-engine is like that already described in the last chapter. The action of the fly-wheel causes the piston to move outward, and this causes suction which draws the charge, through the carburetor, into the cylinder. Then the valves close, the piston moves back and compresses the charge, and, finally, the charge is ignited and moves the piston forward on its working stroke. The exhaust-valve then opens, and the impulse of the fly-wheel carries the piston back toward the head of the cylinder—ready for the beginning of another suction stroke.

Reference again to Fig. 122 and the accompanying description in the previous chapter, will make clear just what occurs at each of the four stages of the cycle: suction, compression, firing, and exhaust. Four strokes in each cycle and only one of these a working stroke! Not only is there but one working stroke, but the three other strokes consume energy which must be subtracted from that given out during the working stroke before we have a net result that can be applied to useful work.

A heavy fly-wheel is, of course, necessary as well as a powerful explosion on the working stroke. The fly-wheel must absorb as much of the energy of the working stroke as is necessary to carry the piston through three other strokes against the resistance—first, of back-pressure from the exhaust, next against atmospheric pressure in producing suction, and, finally, against the resistance to compression, on the third stroke, which is the greatest of all. Small but heavy fly-wheels are used as they are better calculated, than large ones, to take up the energy of a sudden impulse

and distribute it over non-working strokes. We can hardly call the non-working strokes "idle strokes," for they are performing useful service in preparing necessary conditions for the final working stroke.

Neither is the energy wasted that is employed in compressing the charge preparatory to the working stroke, for, as has previously been stated, the extra force of a compressed charge more than makes up for the energy consumed in compressing it.

THE FOUR-CYCLE GASOLINE-ENGINE. Fig. 125 is a sectional view of a four-cycle gasoline-engine with the

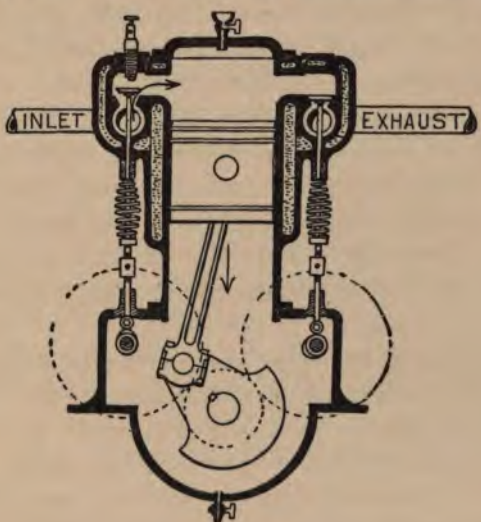

FIG. 125

T-type of cylinder. The fly-wheel, carburetor, timing and lubricating devices are omitted for the sake of clearness.

The cylinder has two projections on opposite sides of the head, like a letter T, one of which carries the inlet valve and its gearing and the other the exhaust-valve. These two projections, together with that part of the cylinder which is not filled by the piston when at the upper limit of its stroke, form a small combustion-chamber, which some manufacturers regard as necessary; but the principal advantage of this arrangement is that it allows a very simple and direct connection for operating the valves, which are mounted on vertical stems extending downward. Attached to the lower ends of the valve-stems are extensions with rollers which rest upon cams by means of which the valves are opened at the right time.

The valves are held in closed positions, when not raised by the cams, by means of heavy coil springs attached to the valve-stems. The extensions are connected to the valve rods by means of couplings with right and left hand threads, or some other similar device, in order that any slack may easily be taken up.

A water-jacket covers not only the working part of the cylinder, but the valve cages on either side. Above the valves are plugs that may be removed when it is desirable to examine the valves.

Ignition is produced by means of a spark-plug, directly over the inlet valve, which is connected with an electric current and timing device, not shown in this figure. The crank case, to which the cylinder is attached, is a hollow casting, which is often made of aluminum alloy for the sake of lightness.

On either side are projections which carry the camshafts which operate the valves. In some engines the

oil, which naturally gravitates to the bottom of the crank case, is splashed about by the crank and connecting-rod at each revolution, and thus serves to lubricate the bearings.

In the figure, the inlet valve is shown wide open, and the piston is moving downward. This is, then, the suction stroke. When the inertia of the fly-wheel has carried the piston to the bottom of its stroke, the inlet valve will close. The fly-wheel will then cause the piston to ascend, compressing the charge; the spark will then occur, and the piston will be driven downward on its working stroke. The exhuast-valve will then open and the piston will ascend ready for the next suction, or charging, stroke.

Inasmuch as the valves open only once in two revolutions of the engine the simple device of a spur-gear on the crank-shaft operating two other spur-gears of twice the number of teeth—one on the cam-shaft operating the inlet valve and the other on the one operating the exhaust-valve—gives the valve motions required. The spur-gears, which are usually enclosed in a separate gear case outside the crank case, are indicated in the figure by dotted lines only. The dotted circles correspond to the pitch circles of the gears, and the two large ones are just twice the diameter of the one on the crank-shaft.

The L-Type of Cylinder. In what is known as the L-type of cylinder, the outlet and exhaust valves are placed side by side, and only one cam-shaft is used. In this case the inlet and exhaust cams must, of course, be set at different angles.

This arrangement is more often used than that shown

in Fig. 125, but it does not lend itself so readily to explanation by means of a diagram. Fig. 126 shows the top view of a cylinder, of the L-type, and the axis of the cam-shaft.

VALVE-IN-HEAD CYLINDERS. Some manufacturers claim great economy in the use of "valve-in-head" cylinders. They point out that the spaces over the inlet and exhaust valves, characteristic of the T and L types of cylinders, have to be filled with gas at every suction stroke which does not materially aid in the production of power. They claim that real economy is secured by eliminating this waste space in the manner shown in Fig. 127, where the inlet and exhaust valves are contained in cages inserted in the cylinder-head.

FIG. 126

The chief objection to this arrangement is that it does not lend itself readily to simple valve-gearing. It is necessary either to run the cam-shaft over the top of the cylinder—as is done in the case of the multiple-cylinder Liberty Motor—or to use rocker-arms to reverse the motion of push rods, as shown in Fig. 127. The greater the number of rods and levers the greater are the chances of wear and noise due to lost motion; but it is significant that some of the

FIG. 127

best automobile and airplane engine builders prefer this arrangement to any other.

Valve-in-head motor uses a single cam-shaft, like that used in the L-type, for operating both inlet and exhaust valves.

In actual practice, the arrangement of a roller mounted directly on the extension of the lift rods, as shown in Fig. 125, is now seldom used.

Cam-shaft rocker-arms, like that shown in Fig. 128, are much smoother in action. The roller is here mounted at the end of a short horizontal rocker-arm which moves on an axis parallel to the cam-shaft. The arm which operates the lift rod may be in line with that which carries the roller, or attached at the opposite side of the bearing, as shown at the top, Fig. 128.

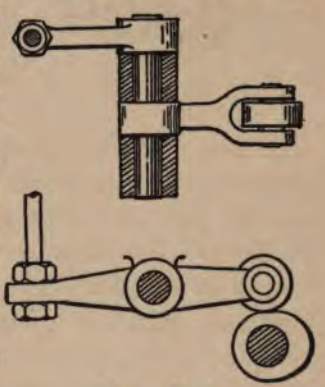

FIG. 128

In starting a gasoline-engine it is often found desirable to introduce a few drops of liquid gasoline directly over the piston, where it serves to enrich the charge. In Fig. 125 a pet-cock with a funnel attachment is shown in the cylinder cover for this purpose.

The gasoline-engine is so similar in general construction to the gas-engine that no further general description is deemed necessary, until we come to the study of multiple-cylinder types.

THE CARBURETOR. One of the important accessories of the gasoline-engine, the carburetor, calls for a special detailed description. Fig. 129 shows, diagrammatically, one of the simplest forms of this device.

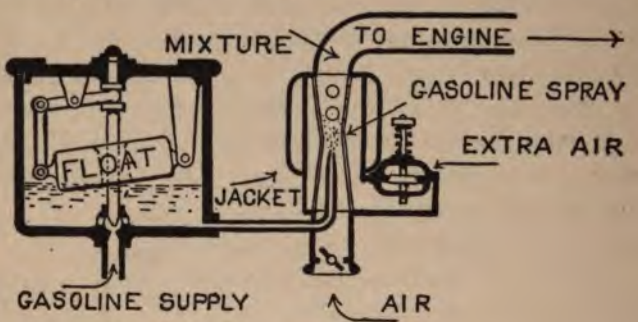

FIG. 129

The carburetor converts liquid gasoline and common air into the explosive-gas that operates the engine. A spray of gasoline is injected into a funnel through which a current of warm air is passing and the two become mixed and form the charge. This seems simple, but it is only when the gasoline and air are mixed in just the right proportions that an easily exploded mixture is obtained. The current of air is caused by the suction of the engine as the piston moves forward on the charging stroke. When the engine is being started the suction is light; when the engine is running rapidly the suction is very strong. There are certain limits within which the proportions of gasoline and air may vary and still produce an explosive mixture, but beyond these limits no explosion will occur. Gasoline vapor mixes with hot air

much more readily than with cold air. So it is generally much more difficult to get a gasoline-engine started than to keep it running after it gets warmed up. The same proportion of gasoline to air that is necessary to use in starting an engine would be very wasteful for one running rapidly.

When black smoke is seen issuing from the exhaust of a gasoline-engine, it indicates an excess of gasoline in the charge. When this occurs there is not only a waste of fuel, but less power is actually developed than there would be with a mixture containing a smaller proportion of gasoline.

Now, let us see how the carburetor is arranged to overcome these difficulties.

At the left, Fig. 129, is shown a small cylinder with a pipe and nozzle leading from one side. This vessel is supplied with liquid gasoline through a small opening at the bottom fitted with a needle-valve. The vessel contains a float with a hole through the middle. This float has projecting lugs which engage short rocker-arms, pivoted to solid supports, engaging a spool fixed to the needle-valve stem. It will readily be seen that an upward movement of the float will cause the needle-valve to move downward. This device is used to keep the supply of gasoline in the vessel nearly level at all times, so as to give an even spray at the nozzle. If too much gasoline enters the vessel, the float will rise and close the needle-valve and keep it closed until the level is lowered slightly and the needle-valve again opens.

The nozzle discharges into a funnel of thin metal.

The bottom of this funnel is connected with an air-supply pipe in which is a damper for regulating the air supply. The top of the funnel is connected with the engine inlet pipe.

Surrounding the funnel is a metallic cylinder connected with an extra air-supply pipe provided with an inlet valve. Outside of all is a space enclosed by a third cylinder which is closed at top and bottom, but connected with a warm-air supply pipe—not shown. The inner funnel has holes in the sides through which air may be drawn from the extra air-supply. The extra air-valve is generally held against its seat by means of a light spring.

The suction of the engine, during the charging stroke, causes a strong draft of air through the funnel; this tends to convert the jet of gasoline from the nozzle into a fine spray which mixes with the air and produces the explosive mixture. With the height of gasoline in the vessel at the left maintained nearly constant, the jet of gasoline does not vary as much as the current of air through the funnel into which it is discharged. By changing the position of the damper the amount of air drawn in may be easily controlled, and the proportions of gasoline and air that give the strongest explosive mixture may be found by trial.

Starting a Gasoline-Engine. Difficulty is often encountered when a cold engine is to be started. The funnel of the carburetor is then generally cold and the gasoline spray does not readily mix with the air. This difficulty is usually overcome by priming. That is to say, by injecting an extra quantity of gasoline into the

charge either through the carburetor or into the cylinder itself.

By using a considerable quantity of gasoline and checking the air-supply, enough vapor will usually be introduced to make an explosive mixture even though the air be cold. Of course, the engine must be turned over by hand, or by some other means, until the air in the cylinder is expelled and a charge is drawn through the carburetor and compressed, ready for the working stroke. If the first charge drawn through the carburetor does not explode, it may be necessary to turn the engine over several times in order that the non-explosive mixture may be expelled and another charge drawn in. Each time a new trial is made, the proportions of gasoline and air should be changed by manipulating the primer or the air-valve. Sometimes too much gasoline is used, and the engine becomes "flooded." When this occurs it becomes necessary to expel the excess of gasoline before an explosive mixture can be secured. After an engine has made two or three successive explosions, it usually begins to draw strongly, and the heat of the exhaust begins to circulate through the jacket of the carburetor; the air in the funnel is warmed up; the gasoline spray is more readily absorbed, and the chances are that the engine will immediately "pick up" speed and continue in motion. When the engine is once well under way, it generally becomes necessary to change the proportions of the mixture, either by decreasing the gasoline-supply or by increasing the air-supply. The primer is first closed, and the damper in the air pipe is usually opened wider.

This gives a "leaner" mixture. That is to say, one with a smaller proportion of gasoline. Generally speaking, the faster an engine runs the leaner the mixture may be. When the engine is running at high speed, it pumps an enormous quantity of air through the carburetor, and if the same proportions were maintained that are employed in starting the engine, the gasoline tank would soon be emptied.

When the draft of air becomes very strong, the suction raises the extra air-valve and more air is drawn into the funnel through the holes shown near the top. This dilutes the mixture and produces a condition better adapted to high speed.

It must be understood that the carburetor just described, and illustrated by the diagram, is only one of many forms. The diagram is intended only to show the most essential parts and the method of changing the proportions of the mixture to suit the different circumstances of starting, moderate speed, high speed, etc. Its proportions are not necessarily exactly what they should be to produce the best results.

A good carburetor must have adjustments for mixing gasoline vapor and air in the right proportions to produce an explosive mixture under varying conditions.

The condition of the atmosphere often affects the working of a carburetor. A moist atmosphere is generally more favorable than a very dry atmosphere. For this reason a gasoline-engine will often run better on a damp day than on a dry one, or better in the evening than at midday.

Carburetors should have adjustments for accurately

gauging the flow of gasoline as well as that of the air. Certain adjustments can best be made when the engine is not running, but it is generally necessary to start the engine afterward to test the adjustment. When certain fundamental adjustments have been made and the relative flows of gasoline and air have been fixed within proper limits, it should still be possible to make other adjustments, such as the control of the air-supply while the engine is running.

The carburetor is an extremely delicate piece of mechanism; and, as it is the very heart of the gasoline-engine, it should be looked after with the greatest care.

The usual form of the carburetor is more compact than that shown in Fig. 129 and the various parts are not always so easily distinguishable; but they will all be found, on examination, to comprise the same essential elements that have been described, namely, an arrangement for furnishing a regular flow of gasoline through a very small nozzle which discharges into a current of air—preferably warm—that is being drawn in by the suction of the engine.

The other parts of the carburetor are usually mere appliances for changing the proportions of the explosive mixture, as circumstances may require.

MANIFOLDS. It is generally desirable to have the carburetor very near the cylinder-head, but in multiple-cylinder engines it is not possible to have a single carburetor equally near all the cylinders. In such cases the mixture passes through a "manifold" in going from the carburetor to the cylinders. The mani-

fold has a single inlet connected with the carburetor and a separate branch to each cylinder. A similar arrangement is necessary for the exhaust, and, as it is an advantage to keep the mixture as warm as possible, the inlet and exhaust manifolds are often placed close together so as to take advantage of the heat of the exhaust.

It is, of course, important that there shall be no leaks between the carburetor and the cylinder. Otherwise cold air will be drawn in from the outside, and the mixture will be both cooled and diluted before it reaches the cylinder. In the case of automobiles, there is often danger of the manifold becoming loosened, and leaky joints occurring where the manifold joins the cylinders.

Sometimes the gasoline tank—especially on automobiles—is more conveniently placed below the level of the carburetor. It is then necessary to use a vacuum tank, or some other device, for supplying the carburetor at constant pressure.

Firing. Not only is it necessary to have the cylinder charged with a mixture of the right proportions, but the charge must be fired with certainty and at the right time.

We have seen that gas-engines are often fired by means of ignition-tubes, but the modern gasoline-engine is nearly always equipped with an electrical device, by means of which a hot spark is produced at the right instant within the body of the charge. The burning of the mixture is so rapid that we call it an explosion and think of it as instantaneous. It does,

however, take a short interval of time for a charge to become ignited and its full heat energy developed.

A gasoline-engine may be making ten revolutions per second, in which case the whole working stroke is performed in one-twentieth of a second, but even this short space of time suffices for the burning charge to do its work—provided the spark has occurred at the right instant.

With an engine moving at high speed, the spark must occur before the piston begins to move forward on the working stroke, otherwise there will not be time for the charge to become thoroughly ignited before the end of the stroke, and energy will be wasted.

GASOLINE-ENGINE DIAGRAMS. Fig. 130 shows three

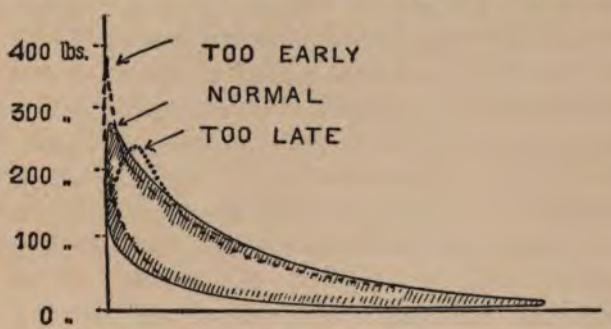

FIG. 130

gasoline-engine indicator diagrams overlapping so as to show the effects of varying the time of ignition with regard to the position of the piston.

The shaded portion shows the effect of ignition occurring at the right time; the dotted line shows the

effect of too late a spark; and the broken line, where the spark occurred too early.

Beginning at the right and tracing the lower line of the shaded diagram toward the left, we see that it rises under the compression stroke, gradually at first and more rapidly toward the end, until it has reached a pressure of more than one hundred pounds to the square inch. Then the spark occurs, and the charge takes fire. The pressure almost instantly rises to nearly three hundred pounds to the square inch. As the piston moves toward the right on its working stroke, the pressure of the expanding gas drops as indicated by the top line of the diagram, rapidly at first and more gradually toward the end, according to the law of expansion of gases, until it reached a point not much above the zero line at the end of the stroke.

It has already been explained that the area of an engine diagram indicates the amount of energy put forth during the stroke. The diagram under consideration shows an economical use of fuel, for while the pressure drops rapidly it continues to the end of the stroke, where it reaches something like atmospheric pressure.

The dotted line shows the effect of timing the spark so that it occurs at the instant that the piston begins to move forward on its working stroke. Though the pressure never rises so high as in the case just considered, it continues to rise during the first eighth of the stroke, and then drops more suddenly than in the normal case. The reason for this is, that there is not time after the spark occurs for the charge to become thoroughly ignited and to put forth its full energy be-

fore the end of the stroke. Another drawback to the use of a late spark is that a large amount of the heat, developed by the ignition of the charge, is carried over toward the end of the working stroke, where it tends to overheat the cylinder and the water-jacket, instead of doing useful work.

Though the spark should always occur before the end of the compression stroke, in order that the charge may be fully ignited before the working stroke begins, there is such a thing as having it occur too early, as shown by the broken line in Fig. 130.

The pressure here rises too high before the compression stroke is completed; and, at the beginning of the working stroke, it has already expended so much of its energy that it drops almost instantly to a point below normal pressure, when the piston begins to move forward on its working stroke.

Not only is the total amount of useful energy expended in this case less than normal, but hurtful stresses are produced on the engine. There may even be danger of rupturing a cylinder in case of too early a spark. It is especially important not to have the spark too far advanced as the engine slows down, for too heavy pressure at the end of the compression stroke may entirely neutralize the effect of the working stroke.

Electric Sparking Devices

We now have to consider how electric sparks may be produced and properly timed.

The subject of electricity cannot be discussed very fully in this place, but some knowledge of electrical

phenomena is necessary in order to understand the working of sparking devices.

Every object is supposed to be possessed of a certain amount of electricity in a quiescent state, but it is only when a flow, or current, from one body to another occurs that we can make any use of it, or become aware of its presence. Two kinds of electricity are recognized and these are designated by the plus and minus (+, —) signs. Whether minus electricity is really a different kind or only a lack of a normal quantity of plus electricity we do not know positively; but we do know that positive electricity is always seeking negative electricity, and, if a body charged with the former is brought into contact—either directly or by means of a good conductor—with the latter a current is set up which tends to neutralize the two.

There are various ways of generating electricity, but the simplest practical method is by means of a galvanic cell. Fig. 131 shows a section of a common "dry cell." It is made up of a thin cylinder of zinc—usually covered inside and out with paper—and a stick of carbon inserted in the zinc cylinder and separated from it by a kind of paste covered with a layer of pitch. Metallic screws, called terminals, are attached to the zinc and to the carbon with thumb-nuts for securing wires.

So long as these terminals are not connected, no electricity will be generated; but let them be connected by means of a copper wire or some other good conductor and chemical action immediately starts up between the zinc and the paste, and a current is produced which passes first to the carbon, thence to the

positive terminal, attached to it, and finally through the wire connection back to the negative terminal and the zinc plate. A single cell will generate about one volt of electricity, whatever its size, but a large cell will generate a greater *quantity* than a small one.

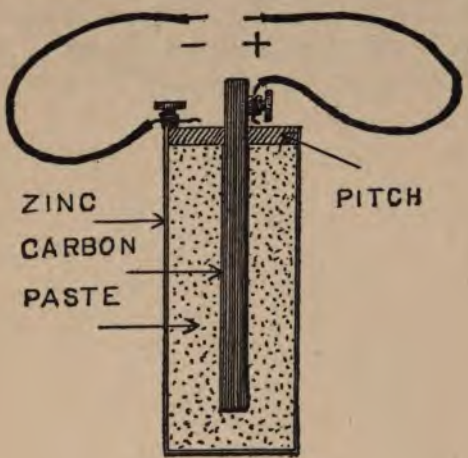

FIG. 131

So long as the wire connection is maintained the current will flow from the positive to the negative terminal, but no spark will be produced. Let one end of the wire be separated from its terminal, however, and a small spark will be produced at the moment of separation. The spark is produced in the effort of the current to continue to flow, but it is always very weak in such a case and ceases entirely when the wire has been separated from the terminal by an appreciable distance. Such a spark would not be sufficient to fire an ordinary gasoline-engine charge; but it may be

increased, both in intensity and quantity, by means which will now be described.

Fig. 132 shows the top views of six dry cells con-

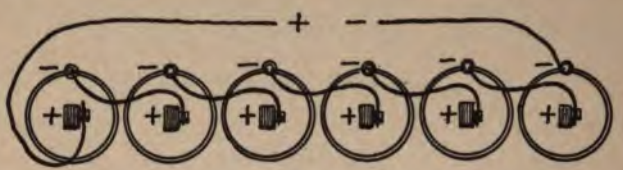

FIG. 132

nected "in series." That is to say, the negative terminal of one is connected with the positive terminal of the next, and so on to the end of the series.

If the ends of two wires attached to the positive terminal of the first cell and the negative terminal of the last cell are brought together, a current of six times the intensity of a single cell will be produced—as will be evident when the wires are again separated.

When it is desired to increase both the intensity and the quantity of the current, cells are connected in the manner shown in Fig. 133. Here there are two sets of cells, connected in the same way as shown in Fig.

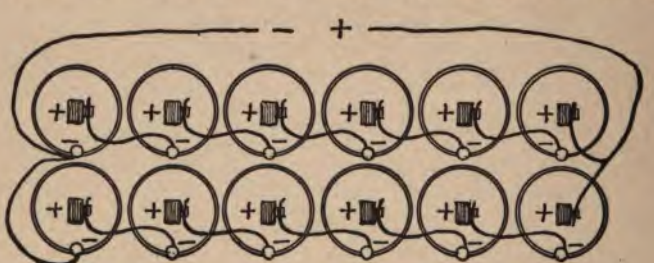

FIG. 133

132. The positive and negative terminals of the two sets are then joined together and connected with terminal wires, as shown in the figure. Such a combination will have the same voltage as the series shown in Fig. 131 but will generate double the quantity of electricity in a given time. This method of connection is called "in series parallel."

Good and Poor Conductors. Some substances, like metals and water, are good conductors of electricity while others, like wood, rubber, porcelain, and dry air are poor conductors. Copper wire is one of the best conductors and rubber one of the poorest. Copper wire covered with rubber insulation is, therefore, generally used for electric circuits. If the wire were not covered with some poor conductor, some of the current would "leak" into the moisture of the air, and the main current might be entirely diverted by any good conductor, like another wire, coming in contact with the first.

The Make-and-Break System. We have seen that a spark is produced whenever wires connected with the positive and negative poles of a battery are first brought together and then suddenly separated. This principle has been taken advantage of in what is known as the "make-and-break" system of ignition. Two metallic parts or poles, one of which must be capable of motion, are placed in the combustion-chamber of the engine. The movable part is connected with the mechanism of the engine in such a way that it is brought first in contact with the fixed part, so as to complete an electric circuit, and then suddenly separated from it at the right instant for producing a spark. In such

an arrangement it is necessary to use great care to insure perfect insulation, and the mechanism for producing the break is generally more or less cumbersome. So this method, once quite generally used, has now gone almost entirely out of use in favor of what is known as the "jump-spark system."

THE JUMP-SPARK SYSTEM. In the make-and-break system the terminals must first be brought into contact to start the current. In the jump-spark system the terminals are not brought into contact at all, but the current must jump across a small gap separating the two poles. This requires a current of much higher tension than that used in the make-and-break system. Methods of reinforcing an ordinary current, so that a spark may be produced, will presently be described, but let us now examine the construction of a "spark-plug"—the device commonly employed to ignite the charge in a gasoline-engine.

THE SPARK-PLUG. Fig. 134 shows a section of a common spark-plug. Two short wires, insulated from each other by means of a porcelain centre-piece, are brought very close together at their outer ends. One of these wires is connected with the body of the metallic plug which screws into the cylinder or combustion-chamber. The other passes through the porcelain and is connected with a binding-screw at the top.

FIG. 134

When one pole of an electric circuit is connected with the binding-screw and the other pole with the metal of the engine a complete circuit is formed—except for the

tiny gap between the wires. If the current has sufficient tension it will jump this gap and produce a strong spark. Spark-plugs must be kept always clean and free from carbon and oil, otherwise the current will find a good circuit without the necessity of jumping the gap and no spark will be produced. The porcelain is shaped so as to bring as much non-conducting surface as possible between the metal of the plug and the central terminal.

THE INDUCTION COIL. In order to reinforce the current sufficiently to make it jump the gap, an induction coil is used.

An induction coil is a device by means of which magnetism is made to lend its aid to electricity in producing some desired result. Magnetism and electricity are closely related, but of somewhat different nature. Everybody is familiar with the common horseshoe-magnet which attracts soft iron, iron filings, etc., and holds them with considerable force.

These magnets are of hardened steel and they retain their properties for an indefinite time. Soft iron, on the contrary, only holds its magnetism temporarily, while in contact with another magnet or while an electric current is passing around it. Not only will an electric circuit produce a temporary magnet out of a piece of soft iron in the form of a core, within a coil of wire through which the current is passing, but the magnetism of the core can be made to produce a current in another coil of wire wound about the same core. It is only while gaining or losing its magnetism, however, that a soft-iron core has the power of causing or "inducing" a secondary current.

Fig. 135 shows a soft-iron core surrounded by two coils of wire. One of these coils is of heavy wire connected with a battery and a switch for making or breaking the circuit. The other coil is of finer wire, and its two ends are connected with the poles of a common

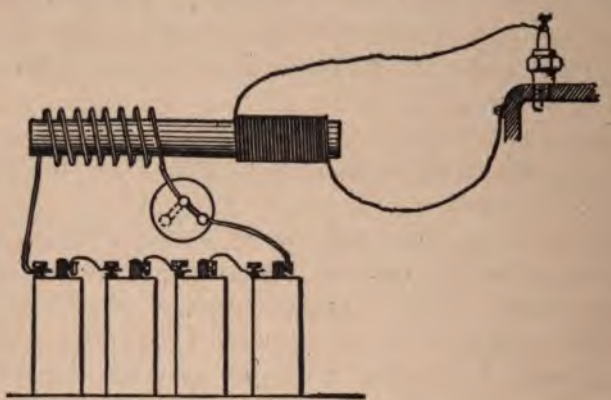

FIG. 135

spark-plug. If the battery circuit is closed, as shown in the figure, the current passing around the coil of heavy wire will turn the core into a temporary magnet. Now, if the circuit is broken, by means of the switch, the magnetism will die away in the core; and, while this is taking place, a current will be induced in the other coil. If the battery is sufficiently strong, a good spark will be produced at the spark-plug. If the switch is again closed the core will induce another current in the secondary coil while it is gaining magnetism—just as it did before while losing its magnetism. Whenever

the main circuit is opened or closed a spark will be produced between the poles of the secondary circuit—but only for an instant, while the core is either acquiring or losing its magnetism. Instead of having the two coils at opposite ends of the core, it is a more usual arrangement to have the primary coil wound rather closely around the core, but insulated from it, and the secondary coil—which is always of fine insulated wire—is then wound, in many coils, on the outside of the primary coil. This arrangement is more compact, and it operates in the same way as that shown in Fig. 135. Of course it is necessary not only to have the wires so insulated that the various coils never actually touch each other, but the primary and secondary coils must also be insulated from each other.

The induced current, in the secondary circuit of an induction coil, is always of higher tension than that of the main circuit—though it is small in quantity and brief in duration. It is, therefore, better adapted to the purpose of producing a spark than the primary circuit.

Even in the old make-and-break system, an induction coil was generally used to give a more intense spark. In the jump-spark system it is an absolutely necessary part of the sparking device.

The Vibrator. The fact that a current can be produced in the secondary coil only when the magnetism is gaining or dying away in the core, has led to an invention by means of which a nearly constant current—of high intensity but low in quantity—can be kept up in the secondary coil.

Fig. 136 shows such a device. A core is wrapped about with a primary coil, one end of which is connected with the positive pole of a battery and the other end of which is attached, by means of a binding-screw, to a steel spring at the end of which is a small

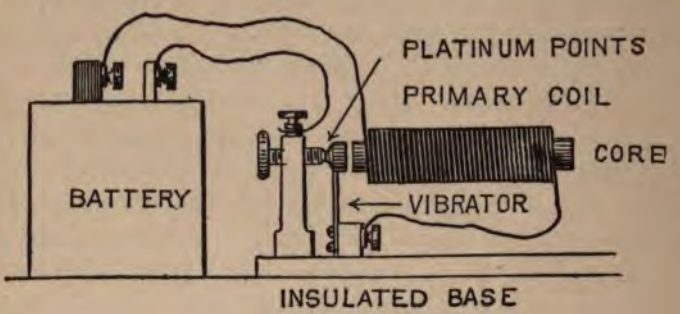

FIG. 136

head directly opposite one end of the core. Opposite the head on the steel spring is a binding-post, fitted with a binding-screw, and an adjusting-screw. The binding-screw is connected with a pole of the battery by means of a wire. The adjusting-screw is for the purpose of limiting the motion of the vibrating spring. Platinum points are provided on the end of the adjusting-screw and on the back of the vibrator. When these points are adjusted so as to touch, as shown in Fig. 136, the battery circuit is completed and a current will flow through the coil. This magnetizes the soft-iron core and it attracts the head on the vibrator; this breaks the circuit and stops the current. The core then loses its magnetism, and the spring

pulls the head away from the core and the platinum points again come in contact. This closes the circuit again, and the core again attracts the vibrator, only to release it as the circuit is again broken, and so on. When the adjusting-screw is set properly, the vibrator will keep up a rapid motion, and the iron core will be magnetized and demagnetized many times each second.

Let us suppose, now, that a secondary coil of fine insulated wire be wound around the outside of the primary coil. Every time the core is magnetized or demagnetized, a current will be set up in the secondary coil. In the case illustrated by Fig. 135, with a constantly moving vibrator substituted for the simple electric switch, there shown, the secondary current will be practically continuous, though, as a matter of fact, it will move in opposite directions according as the core gains or loses magnetism.

The fact that a practically continuous high-tension alternating current can thus be kept up in a secondary coil is of great value as a means of ignition. Instead of it being necessary to start a secondary current and then break it, every time a spark is required, a timing device attached to the secondary circuit of a vibrating induction coil can be made to give contact only when a spark is required.

Fig. 137 shows, diagrammatically, the essential parts of a complete sparking device for a one-cylinder gasoline-engine.

First there is a battery and primary coil fitted with a core and vibrator. A secondary coil connects with the spark-plug and the metal of the engine. A timing de-

vice attached to the secondary circuit is geared up with the mechanism in such a way that contact is made at the instant when the spark is required.

For a multiple-cylinder engine it is only necessary to vary the device by having contact points for each

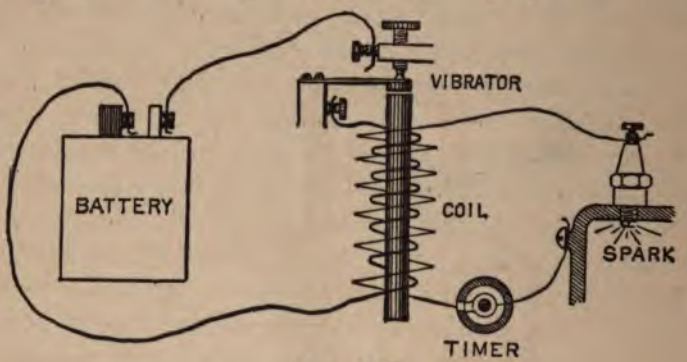

FIG. 137

cylinder. In a revolving timer this can easily be arranged by having as many contact points on the insulating ring as there are cylinders to be fired.

By rotating the timer slightly about its axis, the spark can easily be advanced or retarded to suit the speed of the engine.

THE TWO-CYCLE ENGINE

The four-cycle system, which we have thus far been considering, is the one in most common use, because of its dependability. Providing, as the system does, for full charges of the explosive mixture and high compression, each working stroke is pretty sure to deliver its

full share of energy. A considerable number of valves and other working parts are, however, necessary, which must be accurately machined and fitted. A simpler form of gasoline-engine, working on the two-cycle principle, though somewhat less efficient than the

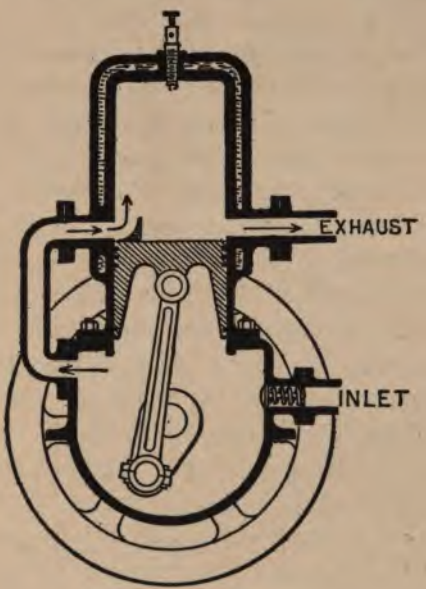

FIG. 138

four-cycle engine, is often used where only a small amount of power is needed. Fig. 138 shows the construction of a simple form of the two-cycle engine.

The cylinder is mounted on a hollow gas-tight crank case having an inlet valve and a by-pass connecting

with the cylinder, as shown. When the piston is in its lowest position, the cylinder end of the by-pass is open, as is also an exhaust-port directly opposite. The piston itself acts as a valve in opening and closing these passages. The inlet valve is held closed by means of a spring except during such time as it is opened by the suction of the engine.

The method of operation is as follows: As the piston moves upward on the suction stroke it first covers the by-pass and exhaust passages and tends to produce a partial vacuum in the crank case. This causes the inlet valve to open and a mixture of gasoline vapor and air is drawn in. A previous charge is at the same time being compressed in the upper part of the cylinder. The charge is next fired, in the usual way; and the piston, in moving downward, compresses the charge that was drawn into the crank case during the upward stroke. When the piston has reached a point near the bottom of its stroke it uncovers both the exhaust passage and the by-pass opening. The burned gases pass out the exhaust and the partially compressed charge in the crank case rushes through the by-pass and fills the space left vacant by the exhaust. Very soon the momentum of the fly-wheel will have carried the piston back past the openings, the flow of mixture into the cylinder will have ceased, and compression will begin.

Whenever compression takes place in the cylinder, the upward movement of the piston causes suction which draws a fresh charge into the base. When the

piston has reached the upward limit of its stroke and ignition has taken place, the piston is again driven down on its working stroke and compression again takes place in the crank case. While every downward stroke of the piston is a working stroke in a two-cycle engine, it is obvious that there must be more or less mixing of the inflowing charge with the outflowing exhaust. The by-pass and exhaust passages are opened and closed at the same time by the moving piston, and it is of course impossible to prevent the inflowing and outflowing gases from mixing to some extent. This is the weak point of the two-cycle engine. Not only is some of the burned gas pretty sure to become mixed with the incoming charge, and the latter to become diluted, but some of the incoming charge is almost sure to escape through the exhaust passage. A deflector is usually placed on the piston opposite the by-pass opening, as shown in the figure, for the purpose of deflecting the incoming charge toward the top of the cylinder where the accumulating charge is supposed to drive the burned gases before it through the exhaust opening. In the best two-cycle engines the crank case is so proportioned, as compared with the cylinder, that the amount of compression caused by the downward stroke of the piston is just about sufficient to fill the cylinder when the by-pass is opened, without forcing much if any of the charge through the exhaust passage before it closes.

Inasmuch as no valve mechanism is required for this type of engine, the cost of manufacture is lower

than that of the four-cycle type. The two-cycle engine gives fair satisfaction where economy of fuel is not a controlling consideration.

Multiple-Cylinder Engines. The great disadvantage attending the use of the four-cycle engine, the

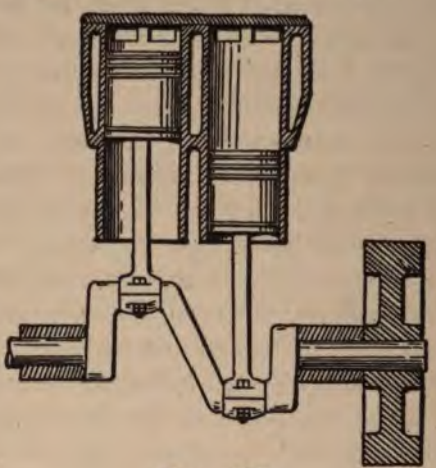

Fig. 139

fact that there is but one working stroke in four, is overcome, in a degree, by multiplying the cylinders and arranging the cranks so that one cylinder will be compressing its charge while another is performing its working stroke.

Fig. 139 is a sectional view of a two-cylinder engine of the four-cycle type. The valves and accessories are omitted, for the sake of clearness. It will be noticed that there are two cranks between a single pair of bear-

ings. In this way the cylinders may be placed close together. The cranks are placed "opposite," so that one piston is at the beginning of the stroke while the other is at the end of its stroke. It can easily be seen that the second cylinder will be compressing its charge while the first is being fired, and that the first cylinder will be exhausting while the second is being fired. Again, the first will be drawing its charge while the second is exhausting, and will be compressing its charge while the second is drawing its charge. A heavy fly-wheel is still necessary, to even up the effort on the crank-shaft, but not such a heavy one as is needed for an engine of one cylinder.

By using four cylinders and having two double cranks opposite each other—an arrangement that is very common in automobiles—one cylinder of the four is always performing a working stroke while the other three are respectively exhausting, drawing, and compressing. A four-cylinder four-cycle gasoline-engine has the same action on a crank-shaft as a double-acting single-cylinder steam-engine. That is to say, there is a working stroke for every half revolution, and the action of the fly-wheel is only necessary to carry the engine past the dead centres and to even up the effort on the crank-shaft. However, the fact that the cranks have to be distributed over a considerable distance, lengthwise of the crank-shaft, makes necessary a fly-wheel and relatively heavy crank-shaft.

Fig. 140 shows an end view of a multiple-cylinder engine with cranks one hundred and twenty degrees,

FIG. 140

or one-third of a revolution, apart. This might be either a three or a six cylinder engine, so far as the end view is concerned; but the three-cylinder engine, once rather common, has given way almost entirely to the six-cylinder engine. A three-cylinder engine lacks the advantage that is gained by the use of four cylinders inasmuch as there cannot be a working stroke at all times. By the use of six cylinders, however, not only can it be arranged to have a working stroke taking place at all times, but the working strokes can be made to overlap, to some extent, and dead centres are thus eliminated.

Fig. 141, shows, diagrammatically, the usual arrange-

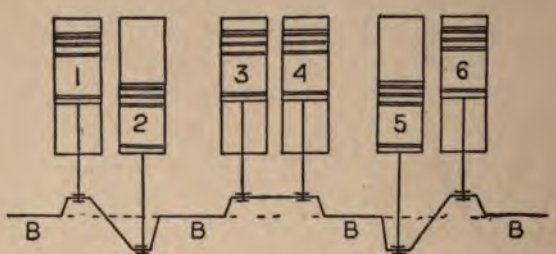

FIG. 141

ment of a six-cylinder engine. Two cranks are usually placed between a set of bearings, but, instead of being opposite, the cranks are one hundred and twenty degrees apart, as shown in Fig. 140. They might, of

course, be sixty degrees apart, but this would involve more machine work and no real advantage would be gained over the arrangement shown in Fig. 141, where two pistons are always in the same relative positions with regard to the stroke, but with different events of the cycle occurring within them. In Fig. 141 pistons 1 and 6, 2 and 5, 3 and 4 are in corresponding positions; but one cylinder in each set of three may be exhausting while its mate is firing, or compressing while its mate is drawing a charge through the carburetor. The firing is not necessarily in the order of the arrangement of cylinders, from left to right, and the timer can be arranged to give a spark in any cylinder where a compressed charge is ready to be fired. Six working strokes are made to occur during two revolutions, or three during every complete revolution. In this way a continuous effort is being made to revolve the crankshaft, notwithstanding the fact that suction, compression, and exhaust are occurring in other cylinders at the same time.

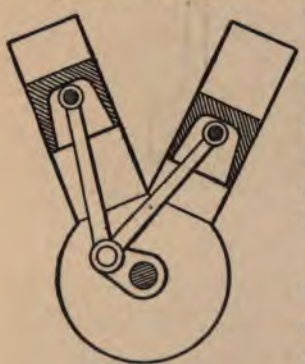

FIG. 142

Fig. 142 illustrates what is called the V-type of cylinder arrangement. This arrangement is much used in airplane engines and in high-grade automobiles.

Generally there are more than two cylinders, but the others are placed in line with those shown in the figures, so they are all in two rows at an

angle of about forty-five degrees with each other. Two sets of pistons and connecting-rods operate a single crank; and dead centres are eliminated as a result of placing the cylinders at an angle with each other. While the piston at the left, in Fig. 142, is just beginning its stroke, the one at the right is half-way through its working stroke. By using four or six cylinders at each angle, the two which operate any one crank may be fired at the same time. One will then always be working to good advantage while the other is working at a disadvantage. With two sets of working strokes, at different angles, occurring at all times, very smooth running is assured even with a very light fly-wheel.

The method of coupling two different connecting-rods with a single crank is illustrated in Fig. 143.

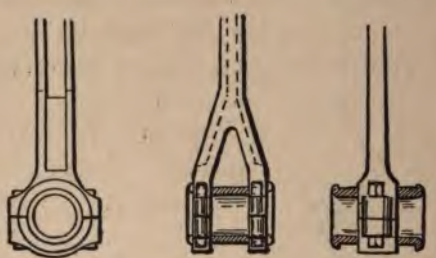

FIG. 143

On the right is shown a connecting-rod of usual shape but with a bushing twice as long as would ordinarily be required. The central figure shows a forked connecting-rod with a bushing of the same length as that

shown at the right. At the left is shown a side view which is practically the same for either form.

Though two bushings are shown, only one is used for the two connecting-rods—one working within the fork of the other. Of course this arrangement involves two sets of bearing surfaces, one on the inside and one on the outside of the bushing. The forked rod must, of course, provide room for the single rod to work within it, without any possibility of the two coming in contact at any point of the stroke.

Circulating Water-Jackets. The cooling of a gasoline-engine is very important, and, as has already been explained, it is generally effected by means of a water-jacket. If the jacket water is not kept in circulation, however, it would soon become overheated and fail to serve its purpose.

Water-jackets are, therefore, provided with inlets and outlets and a system of piping for carrying the water away from the cylinder into a radiator, where it

Fig. 144

is cooled and then returned. The water is generally kept in motion by means of a small centrifugal pump like that shown in Fig. 144.

A small drum-shaped vessel has a pipe connecting

with the middle of one of the heads and another branching off from its outer rim. Within the drum, a small paddle-wheel, shown at the right, is made to revolve rapidly in the direction of the arrow. The water in the drum is thus made to revolve rapidly, and the centrifugal force, which tends always to make a body depart from the centre about which it revolves, causes a flow through the pipe connected with the rim. This tends to produce a vacuum in the drum, and water immediately flows in through the pipe connected with the head.

The paddle-wheel, or fan, is usually mounted on the end of a pump shaft driven from the crank-shaft. A small pump of this description will throw water quite fast when it is revolved rapidly. The pump is usually placed in the pipe connection between the bottom of the radiator and the water-jacket. One good pump is usually sufficient to keep the entire cooling system in operation. Drawing water from the bottom of the radiator tends to produce a vacuum which causes jacket water to flow in at the top. A power-driven fan is often used to draw air through the spaces between the cells of the radiator to facilitate the rapid cooling of the water.

Air-Cooling. Small cylinders are often cooled by air alone, without the aid of a water-jacket. By casting a number of flanges on the outer surface of the cylinder, as indicated by the sectional view, Fig. 145, a large amount of surface is brought into contact with the air and cooling is effected. Airplane and motor-

cycle engines, with small cylinders, are often dependent on rapid motion for a sufficient air-supply, but it is usual to provide a fan for producing a current of cool air against the flanged cylinder.

Inasmuch as large cylinders have a smaller relative surface as compared with their capacity than small cylinders, water cooling is almost always necessary where the cylinders exceed three inches in diameter.

Sometimes the cooling flanges are made of separate circular metallic plates, closely attached to the cylinder

FIG. 145

FIG. 146

and placed near together, as shown in Fig. 146; a larger cooling surface may thus be secured than by the use of cast flanges, but there is greater danger of the flanges becoming bent out of shape and their efficiency being thus impaired.

Another objection to the use of plates is the difficulty of applying them to irregular surfaces, like the extensions of the water-jacket that protect the exhaust passages and combustion-chambers.

The Liberty Motor

Internal-combustion engines, as we have seen, need to be made very strong to withstand the sudden explosions and quick applications of force to the moving parts. Heavy fly-wheels and water-jackets, too, add to the weight and make such engines heavier, as a rule, than steam-engines of like capacity.

When gasoline-engines were first employed to drive airplanes, a difficult problem presented itself, namely, to so design them that they would deliver power enough to raise their own weight and that of the necessary airplane parts. Every effort was made to increase the power for a given weight of engine and parts, but it was some time before an engine was produced that could be depended upon to deliver sufficient power to carry the necessary weights—including the driver and its own fuel—for anything beyond very short flights.

Not many years ago, Bleriot's flight of twenty-two miles across the English Channel was rightly considered a wonderful performance—not only for the driver of the plane, but for the engine that supplied the motive power. If any one had predicted, ten years before that event, that the heavy and cumbersome gasoline-engine of that day would be so improved and lightened that it would be able to carry its own weight through the air—to say nothing of the weight of plane, driver, and the necessary fuel—he would certainly have been regarded as a dreamer who had little knowledge of practical matters.

Not only was Bleriot's feat and his engine performance soon afterward put in the shade by even more wonderful flights, but the great World War stimulated improvements that made it possible for heavier than air craft to carry, in addition to their own weight and the weight of their motors and fuel-supplies, hundreds of pounds of explosive bombs, machine-guns, and men to operate them, in perilous air trips of several hours' duration.

The improvement of war planes had been carried so far by the belligerents of Europe at the time that America entered the war, that many felt that our country had been left hopelessly in the rear in all matters that had to do with navigation of the air. At that time, too, it was realized that victory might depend on supremacy in the air, and that the need of a great increase in Allied planes of superior quality and speed was imperative. If America were to help solve the problem she must not only be able to build as good planes as were being turned out in Europe, but must, if possible, excel all previous performances in the construction of light and powerful motors.

Some of our most capable auto-motive engineers became interested in the problem, and, after a thorough study of the best models of foreign motors, these gentle men went to work with a determination to excel all previous efforts. In a very few months motors were brought out that compared favorably with those that were being produced in Europe. In May, 1917, a conference was held in Washington which reached the conclusion that still further effort must be made to in-

crease the power, as compared with weight, of the best engines produced up to that time. It was concluded that the necessity for a lighter and more powerful motor was so great that smaller factors of safety must be employed than were common in ordinary practice, and that long life was of less importance, in a war-plane engine, than ability to perform unusual feats in a crisis.

A motor had been brought out, by one of our leading automobile manufacturers, that possessed the features most desired, except that it was less powerful than was thought desirable. A factor of safety had been employed, to meet government tests, which made the parts somewhat heavier than the experts at the conference thought necessary. Government requirements as to tests of strength and endurance were somewhat relaxed, and the designers of the favorite engine again went to work, with the aid of other able engineers, to produce a more powerful and lighter motor per horsepower than had ever before been built.

The outcome was the Liberty Motor, in which the remarkable result was obtained of an engine of eight hundred and fifty pounds' weight developing four hundred and thirty horse-power at eighteen hundred revolutions per minute.

This remarkable performance was attained by a single engine, on which the greatest care had been expended in manufacture; but, within a very short time, plans were announced by means of which thousands of engines of like capacity were to be turned out, in quantity production, by various manufacturers in different parts of the country. These plans were car-

ried out, and, at the time the armistice was signed, these wonderful motors were being turned out, at a remarkable rate per day, by a considerable number of different manufacturers. The world was surprised by the rapid production of one of the most successful airplane motors that had yet been manufactured.

Perhaps no better example could be taken of the successful application of mechanical principles to useful results than is found in the Liberty Motor. It is therefore deemed worthy of a somewhat lengthy and detailed description in this connection. If it should seem that the dimensions of some of the parts have been reduced to too low a limit, it should be remembered that the motor has met the test, not only of government requirements, but of actual practice, under war conditions. Let it not be concluded, however, that such dimensions as we find in some of the parts of the Liberty Motor can safely be employed in ordinary practice, for only by the use of very superior material and workmanship can such dimensions be depended upon to give the necessary strength and endurance to the parts.

The Model A Liberty Motor is of the V-type and has twelve cylinders. The bore of the cylinders is 5 inches and the stroke of the pistons 7 inches; the piston displacement of the twelve cylinders is, therefore, about 1.650 cubic inches.

At 1,800 R. P. M. 430 horse-power is said to be developed. The weight of this remarkable motor is given as 850 pounds—less than 2 pounds per horse-power.

Fig. 147 is a general view of the motor, ready for

installation in an airplane. The cam-shafts which operate the rocker-arms, and through them the valves, are placed in housings at the tops of the cylinders, and are driven by gears from the crank-shaft.

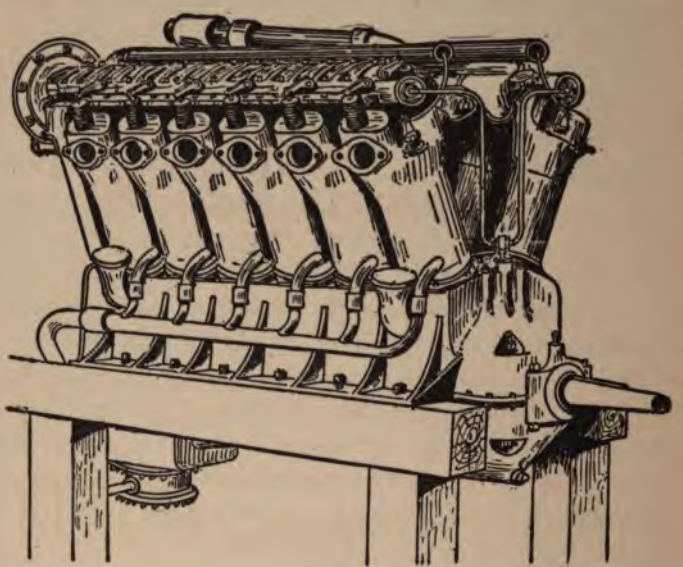

FIG. 147

Fig. 148 shows a pair of rocker-arms mounted in bearings at the top of the aluminum crank-shaft housing—with the bearing cap removed. It will be noted that the construction is light and that the arms which carry the rollers drop into cavities over the cams which are not shown in the figure. The springs on the valve-stems press upward at all times on the valve lever-

arms. This has the effect, when the bearing cap is in place, of pressing the rollers against the cams and preventing any lost motion.

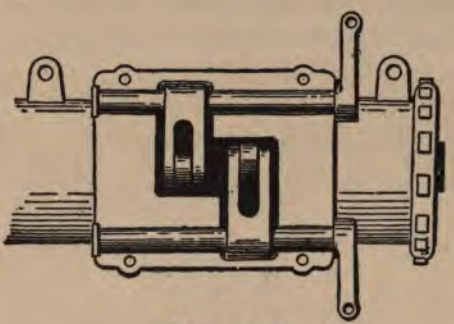

FIG. 148

Fig. 149 shows a portion of the hollow steel cam-shaft. The cams which operate the inlet and the ex-

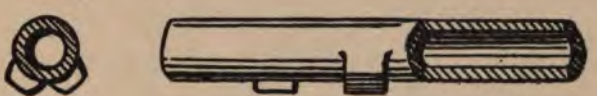

FIG. 149

haust valves are near together on the cam-shaft and each operates a separate rocker-arm, as shown in Fig. 148.

Fig. 150 shows, at the left, the hollow steel forging from which the cylinders are made; at the centre, a finished cylinder without its water-jacket; and, at the right, a view of a cylinder equipped with a water-jacket and ready for mounting on the aluminum crank-case.

It will be noted that the cylinder is turned down until it is very thin except at the upper end, where it has to stand the shock of the explosion. In order to lighten the cylinder by the elimination of every superfluous ounce of metal, the outside of the lower portion is

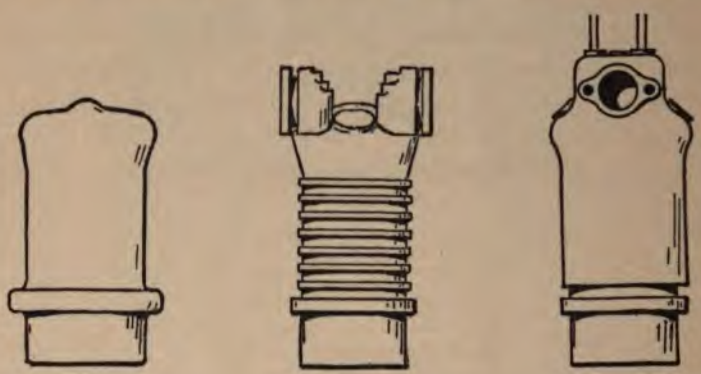

FIG. 150

turned down to a corrugated form with ribs to reinforce the thin walls. The valve housings, shown at the top, are also shaped out of steel and fastened to the top of the cylinder by the electric welding process. The small boss, between the bases of the valve housings, marks the spot where the spark-plug is inserted. This boss must, of course, be attached to the water-jacket case so as to admit of no leakage between them. There are two spark-plugs, one on either side of the valve housings—in order to insure positive ignition in case one of the plugs should become foul. The complete cylinder is shown turned a quarter of a revolution to the right,

so the observer is looking directly into the exhaust opening.

The water-jacket casing is made of two parts of pressed steel welded together by the electric process after the casing is in place. It covers the valve housings and is, of course, as thin and light as it can well be made. The finished cylinder, equipped with valve housings and water-jacket, is considerably lighter than the steel forging from which the cylinder alone is turned.

Fig. 151 shows one of the pistons, which is of the trunk variety, with three sets of spring rings and several

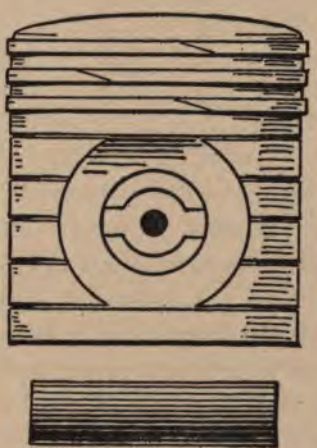

FIG. 151

oil-grooves—lower down. The metal is cut away, as shown, where the ends of the connecting-rod pin meet the outer surface. This is for the double purpose of

lightening the piston and preventing any possible contact of the pin with the cylinder walls.

The connecting-rods are of the kind illustrated in Fig. 143—one straight and one forked working together on a single crank-pin.

Fig. 152 shows a side view, which is practically the same for either the straight or the forked rod. The

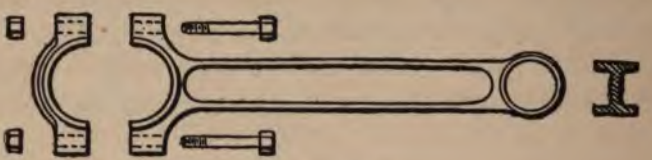

FIG. 152

extreme lightness of the rod should be particularly noticed. It is constructed of the finest nickel-steel, machined on all sides. Every ounce of material that is not necessary for strength is cut away, and that which remains is so distributed as to give strength where it is most needed. The "H" cross-section is, of course, used, for it gives not only great resistance to compression but is the best form to resist bending due to rapid oscillation. The bolts for the cap are made extremely light, as they have only to hold the crank-pin and the lower end of the rod in proper contact. The pressure exerted on the crank-pin, is, of course, always downward—both during compression and on the working stroke. For the same reason the metal which surrounds the piston-pin, at the top of the rod, is also made very thin.

Assuming that the pressure of the exploded mixture at the time of ignition reaches three hundred pounds to the square inch, the pressure exerted on the connecting-rod, through the 5-inch piston, must amount to something like three tons at every explosion. With due regard for lightness, therefore, care must also be taken to leave enough metal in the middle sections of the rod to withstand this tremendous pressure, which is repeated—at the rate of eighteen hundred revolutions per minute—fifteen times per second on every connecting-rod in the engine.

The crank-shaft is, of course, hollow, and every other part is lightened to the greatest degree possible without detracting from the great strength needed to transmit the force of one hundred and eighty three-ton explosions, every second.

Aluminum is used wherever possible and pressed steel, electrically welded, is employed for exhaust and water-jacket manifolds and other like purposes. Fig. 153 shows a section of a manifold which connects the centrifugal water-supply pump with the water-jackets. Like other parts of this character it is made of two parts of pressed steel welded along a longitudinal seam.

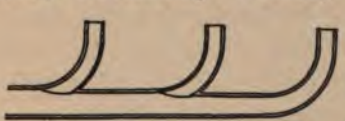

FIG. 153

With so many parts, electrically welded, that must not only be strong but gas and water tight, it is evident that only careful workmen and intelligent and watchful inspectors can be put in charge of such work.

The plate at the beginning of this book is from a photograph of a Liberty Motor, furnished by the United States War Department Air Service.

In order to show the advance that has been made in airplane motors since the Wright Brothers made their first successful flight in 1903, it may be of interest to state that their 12 horse-power engine weighed 152 pounds—or 12.7 pounds per horse-power. In 1910 they used a 54 horse-power motor weighing 308 pounds—or 5.7 pounds per horse-power. The Liberty Motor, of 430 horse-power, weighs 850 pounds—or less than 2 pounds per horse-power.

While the weight of airplane engines has been increasing from year to year, the power developed has been increasing at a much higher rate—both with regard to weight and absolutely. In 1903 the average fuel consumption was .80 pounds per horse-power per hour; in 1914 it was .65 pounds, and, in the case of the Liberty Motor, of 1918, it was reduced to .46 pounds.

CHAPTER X

OIL-ENGINES

THE modern gasoline-engine, as we have seen, is one of the highest products of mechanical science, and the latest types produce a large amount of power for their weight, but they use a high-priced fuel.

Many attempts have been made to produce internal-combustion engines capable of utilizing the more abundant low-grade fuels. The most successful of these are the various types of oil-engines. The ordinary oil-engine operates on the same principle as the gasoline-engine, but has a different carburetor. Mineral and vegetable oils are made up largely of two highly combustible elements, carbon and hydrogen; but these heavy oils cannot be vaporized and mixed with air so as to form an explosive mixture by means of the simple carburetor used on gasoline-engines. Carburetors for kerosene, and other oil-engines, must be provided with some means of heating the elements that go to make up the mixture, in order that the oil may be thoroughly atomized and mixed with air before entering the cylinder. There is a difficulty in starting such engines unless heat can be brought from some source outside the engine itself; they are therefore not so reliable as the gasoline-engine for use under adverse conditions.

The Diesel Engine

Internal-combustion engines are generally found to be more efficient according as they use a more highly compressed charge; but compression causes heat, and a highly compressed charge is liable to explode from its own heat before the end of the compression stroke. This pre-ignition sometimes fractures cylinders, and always causes a great waste of power. In order to prevent injurious pre-ignition, charges are rarely compressed much above one hundred pounds to the square inch, in ordinary internal-combustion engines.

During the last decade of the nineteenth century, Doctor Rudolf Diesel, of Leipsic, brought out an internal-combustion engine which involved in its operation a principle that had never before been applied in practical mechanics. Doctor Diesel understood the value of high compression, and conceived the idea of mixing the fuel and air at the very moment when power is needed for the working stroke. He came to the conclusion that cheap low-grade oils could be utilized as fuel if introduced into a highly heated charge of compressed air at the proper time. He enlisted the aid of manufacturers, and after some experimentation brought out the most economical heat-engine that had ever been produced. The great value of this invention lies in the fact that fuel oils of low grade, and consequent low price, are made available as power producers.

Not only may natural oils be used as fuels for Diesel

engines, but tar-oil, a plentiful by-product of coke and gas manufacture, has been used with good results. Vegetable oils may also be used.

By thus making available great stores of liquid fuel, and using the heat thus generated to drive pistons directly, the potential energy of our natural resources has been greatly increased, and we are placed in a position where we do not need to worry so much about the rapid disappearance of coal. To quote Doctor Diesel's own words: "Further reason for this importance [of the Diesel motor in the world's history] lies in the fact that the Diesel engine has destroyed the monopoly of coal and has in the most general way solved the problem of the employment of liquid fuel for motive purposes. . . . The Diesel motor has thus become in relation to liquid fuel what the steam and gas engine are to coal, but in a simpler and more economical manner; it has by this means doubled the resources of man in the sphere of power development and found employment for a product of Nature which previously lay idle."

In speaking of the results of his experiments in the use of by-products of the manufacture of coke—tar or creosote oil, he adds: "It follows, therefore, that this engine has an important influence on the further industries—gas and coke manufacture—from which the by-products have now become so important that a great movement is beginning in connection with this question. . . . One fact arises distinctly from this movement, namely, that the coal which appeared to be threatened by the competition of liquid fuels will, on the contrary, enter into a new and better era of u

ization through the Diesel motor. . . . Since tar-oil can be employed three to five times more efficiently in the Diesel motor than coal in the steam-engine, it follows that coal can be much more economically utilized when it is not burned barbarously under boilers or grates, but converted into coke and tar by distillation. . . . The coke is then employed in metallurgical work and for heating purposes; the valuable products from the tar must be extracted and used in the chemical industries, while the tar-oil, and its combustible derivatives, and under certain circumstances the tar itself, can be put to exceptionally favorable use in Diesel motors."

Diesel motors differ in operation from gas and gasoline motors mainly in their higher compression and in the fact that the fuel is introduced into a highly compressed, and therefore highly heated, charge of pure air at the very moment when it is needed for the working stroke. Instead of causing a violent explosion, the fuel oil burns rapidly, but steadily, in the cylinder during the early part of the stroke, and thus a nearly constant pressure is caused until the cut-off occurs—usually after about one-tenth of the full stroke has been made. After the cut-off occurs the gas works expansively, like steam in a Corliss engine, until the end of the stroke. The action is, therefore, more like that of steam in a steam-engine than like the action of an explosive mixture in a gas or gasoline engine.

As we have seen, the indicator diagram of a gas-engine shows a high point of pressure at the beginning of the working stroke which falls very suddenly the

moment the piston begins to move. In the case of the Diesel engine, the diagram shows that the pressure remains practically constant until the cut-off occurs. This is because the fuel is burning continuously and the heat of combustion is added to the heat caused by the compression of the charge. After the cut-off occurs there is, of course, a rapid fall of pressure and heat due to work performed by expansion.

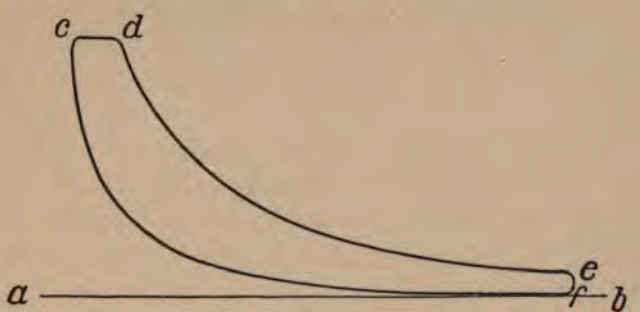

FIG. 154

Fig. 154 shows a typical Diesel engine diagram. The pure atmospheric air that is drawn in during the suction stroke is compressed on the return of the piston—at first gradually and finally to something like five hundred pounds to the square inch—as indicated by the line, *f c*. Fuel oil is then sprayed into the highly heated compressed air and the pressure is maintained at the high level for about one-tenth of a stroke, as indicated by the line *c d*. The fuel valve then closes and the pressure falls, as indicated by the line, *d e*. At the point *e*, the exhaust-valve is opened and the

pressure falls almost instantly to the atmospheric line *a b*.

Diesel engines are built on both the two and the four cycle principle. The same care needs to be taken to get rid of burned gases, as in the gasoline-engine; the suction stroke should take in only pure air, and the fuel oil should begin to be sprayed in at the moment when the spark is usually applied. It should be borne in mind that the heat, necessary for ignition of the charge, is produced entirely by compressing a charge of pure air from atmospheric pressure to something like five hundred pounds to the square inch. In order to secure the high compression required, not only must the piston and valves be very accurately fitted, but the combustion-chamber must be very small, so that the air charge shall be compressed into very little space, when the piston is at the top of its stroke.

Fig. 155 shows a sectional elevation of a vertical single-cylinder Diesel engine of European manufacture. One of the first peculiarities to be noticed is the unusual lengths of the cylinder and piston, the latter having no less than six packing-rings to insure against leakage.

In this case the cylinder liner is a separate casting—shown in black—which fits into the water-jacket cylinder at top and bottom, and is supported at the middle by means of a ring and webs cast integral with the water-jacket cylinder. The cylinder-head, which contains all the valves, is very heavy and has its own water-jacket connected by means of a by-pass—not shown—with the cylinder water-jacket.

One reason given for the use of such a long piston is

that it equalizes the side wear due to the oblique action of the connecting-rod, but this is, of course, no

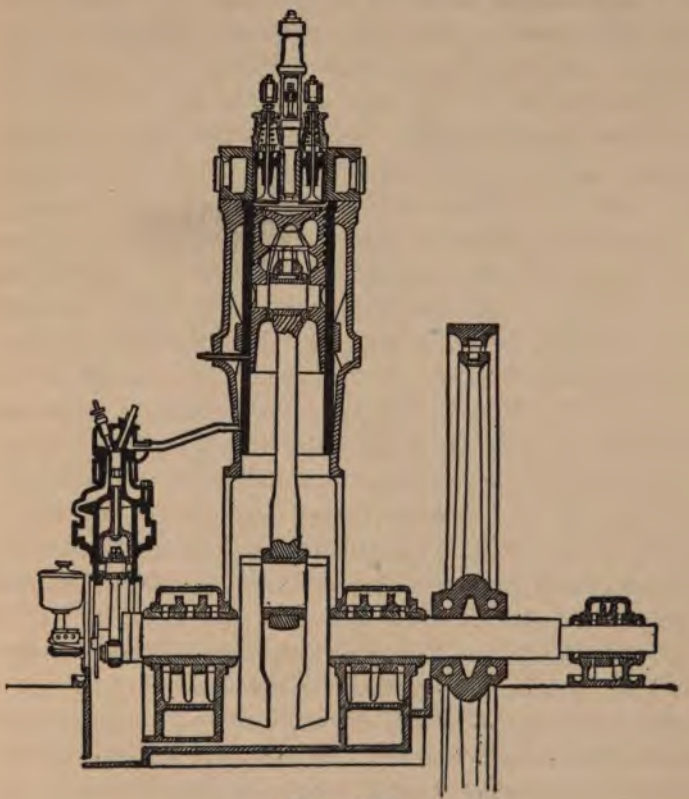

FIG. 155

greater than in the case of an ordinary gasoline-engine. It will be noticed that there are three bearings for the crank-shaft. The small outer bearing is

for the purpose of preventing any sagging on account of the weight of the fly-wheel. The extreme smallness of the combustion-chamber can readily be observed with the piston at the top of its travel, as shown.

Not only is it necessary, with this type of engine, to have very high compression in the cylinder, but an auxiliary air compressor is necessary to provide compressed air for starting the engine and for injecting the fuel oil into the compressed-air charge. Such a compressor is shown at the left, Fig. 155. It is worked by means of a short crank attached to the end of the main shaft. This compressor is fitted with a water-jacket which is connected with the water-jacket of the main cylinder by means of a pipe. The compressor is connected with a tank—not shown—where the compressed air is stored for the purposes that have been indicated. Inserted in the cylinder-head, and shown in sections, are two large valves, of the "mushroom type," opening downward and held against their seats by means of coil springs. One of these is for the admission of pure air, and the other is the exhaust-valve.

Between these valves is shown the fuel valve, which will be described more in detail presently.

On account of limited space the spring for this valve is carried in a special housing, seen at the top of the figure. The cylinder-head is held in place by means of heavy steel bolts, one of which is shown in Fig. 158. These bolts are screwed into the heavy part of the water-jacket cylinder. When we consider that the cylinder and cylinder-head are subjected to a pressure of five hundred pounds to the square inch, at every stroke, it

will be realized that all these parts must be very strong and well fitted.

All the valves are operated by means of bent levers and a cam-shaft attached to the back of the cylinder. The cam-shaft is usually driven from the main shaft

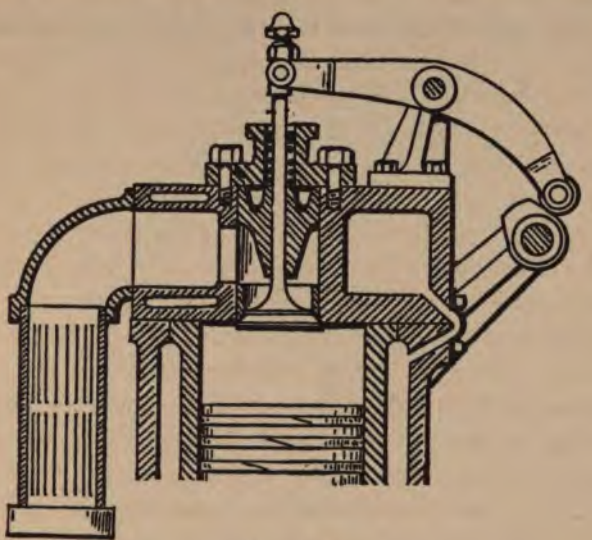

FIG. 156

by means of screw-gearing. Fig. 156 shows a view of an air-valve and its housing. It shows also the arrangement of the cam and lever by means of which it is operated. At the left is shown an elbow and a short length of pipe closed at the lower end. This pipe is pierced all around with saw cuts through which the air is drawn during the suction stroke of the engine, and

by means of which the air is strained of dust. At the right is shown a by-pass for connecting the water-jacket of the cylinder-head with that of the cylinder. The cam which operates the air-valve is of such shape that the valve is held open during the entire suction stroke.

Valve levers are often made with a detachable end,

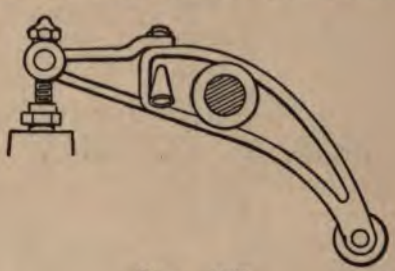

FIG. 157

as shown in Fig. 157, so that the valves may be removed without it being necessary to remove all the valve-gearing.

Besides the three valves already mentioned, a fourth valve called a "starting-valve" is necessary in all Diesel engines. Such a valve is shown at *F*, Fig. 158. Inasmuch as an independent supply of compressed air is always necessary for injecting the fuel oil into the cylinder, all Diesel engines are supplied with compressed-air starting devices which are thrown out of gear by the same arrangement that throws the fuel valve into operation.

Before describing the action of the engine, attention is called to Fig. 159. This is an enlarged sectional

view of the valve which supplies fuel oil to the cylinder at the beginning of the working stroke. The valve proper, shown at *A*, is in the form of a common needle-valve, which closes into a conical recess at the bottom

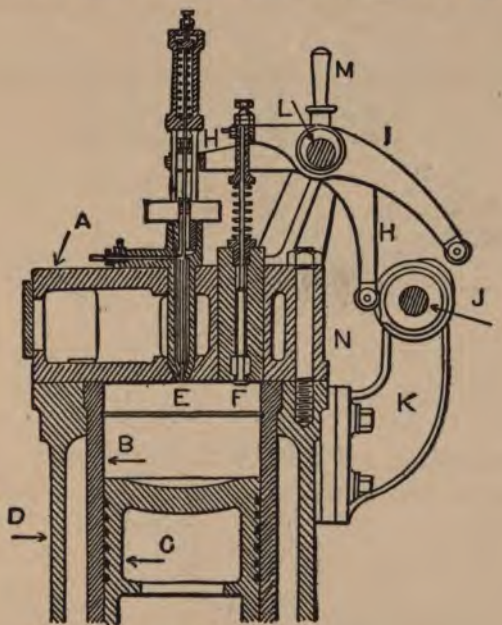

FIG. 158

of the housing. Attached to the bottom of the housing is a mouthpiece, with a very small opening and a wide flare, which connects directly with the cylinder. This causes the oil spray to assume the shape of a wide cone as it enters the cylinder. The valve spindle fits into a tube, *D*, with a conical end which does not quite

touch the interior cone of the valve housing, and leaves a considerable space all around, higher up. It is through this space that the compressed air employed to inject the fuel oil is admitted.

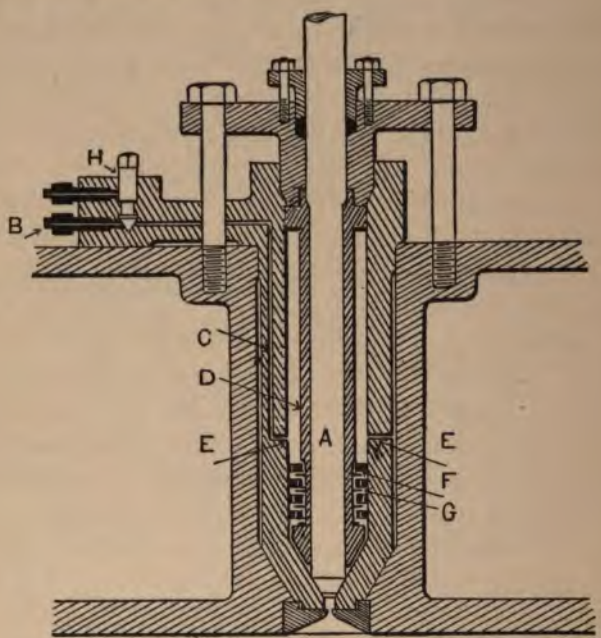

FIG. 159

The oil inlet is shown at *B*. It is very small, and the flow through it is controlled by a governor. A cylindrical passage in the valve housing is connected with the oil inlet and opens into the compressed-air passage by means of passages shown at *E E*. Between these

openings and the needle-valve are several rings with holes drilled through them, as shown at *F*. These holes are not directly opposite each other, and between the rings there are disks attached to the tube, as shown at *G*.

Now, when the needle-valve is raised from its seat, the compressed air carries the fuel oil before it through the small holes and around the edges of the disks into the cylinder. In passing through and around these obstructions the oil is broken up and thoroughly mixed with the air, much as in the case of the carburetor of an ordinary gasoline-engine. The cock shown at *H* is for the purpose of testing and gauging the fuel-oil supply.

It must be remembered that the fuel-oil spray is thrown into a small body of highly compressed air in the cylinder, and that this can only be done by means of a still more highly compressed charge from the compressed-air tank. The compressed air in the tank is often under a pressure of a thousand pounds per square inch. The method of packing the shaft of the needle-valve will be understood from the cut.

Returning, now, to Fig. 158, let us examine the method of operation. Here only the starting-valve and the fuel valve with their gearing are shown.

It will be noticed that the lever *I* is pivoted on an eccentric sleeve and that the roller is not in contact with its cam. The fuel-valve lever *H*, which is also mounted on an eccentric sleeve, is shown in running position. The small cam gives a quick short opening of the fuel valve at exactly the right time for injecting the

oil spray. In the position of the piston shown, the spray has been cut off by the action of the cam and the charge is acting expansively.

Whenever it is desired to start the engine, the lever *M* is thrown down to a horizontal position by hand. This changes the positions of the eccentric sleeves, on which the levers are mounted, and throws the roller on the end of the lever *I* into position to be operated by the starting cam. At the same time it throws the roller on the lever *H* away from its cam. When the starting-valve, *F*, is opened compressed air from the supply tank rushes into the cylinder and moves the piston. This air is so highly compressed that it operates the engine and causes compression on the return stroke, as in ordinary operation.

After a few turns have been made in this way, the lever *M* is thrown back into the vertical position; the lever *I* is thrown away from its cam; the lever *H* is returned to working position and the engine begins to run under its own power.

It must be evident to any one who has followed this description that the Diesel engine is a very fine piece of mechanism, and that it will not work at all unless conditions are exactly right. Extreme care is necessary in its manufacture, as has already been said, otherwise it would be impossible to maintain the high compression required in the cylinder and the still higher compression needed for starting and fuel injection.

It may seem that the power required to produce the high compression of the air charge—five hundred pounds or more to the square inch, or nearly twenty

tons on a 10-inch piston—is wasted, but it must be remembered that this is converted into heat energy which becomes available during the working stroke.

As a matter of fact, the high efficiency of the Diesel engine is due largely to the fact that high compression can be employed without danger of pre-ignition. There is no danger of a premature explosion because there is no explosive mixture in the cylinder until the fuel oil is admitted; even then, no explosion occurs but rapid combustion, and, consequently, even pressure results until the cut-off occurs.

Just as in the case of the gasoline-engine it is necessary to ignite the charge before the beginning of the working stroke, so, in the Diesel engine, it is necessary to inject the fuel into the cylinder a moment before the end of the compression stroke.

Diesel engines do not need to be speeded up so much as gasoline-engines, to show efficiency, for combustion is not so sudden; consequently they do not require so much lead of ignition.

Fig. 160 shows the small cam which operates the fuel-valve. If the valve were to open at the instant that the piston reached the highest point of its stroke, the cam should begin to operate when it reaches the horizontal line, *A C*. Inasmuch as a slight lead is necessary the cam is set a little in advance, so that it begins to raise the fuel-valve at the point *a*. When the cam has revolved through the small arc, between the lines *a* and *b*, the valve is closed and the cut-off occurs. This usually corresponds to about one-tenth of a full stroke. Here, again, is shown the necessity of careful

design and workmanship. The cam must be designed and set to begin and end the valve opening at the right instant without any waste of fuel due to too wide or too prolonged an opening.

Fig. 161 shows the exhaust-cam which is arranged to begin the opening just before the piston reaches the

FIG. 160

FIG. 161

end of its working stroke, and holds the valve open until the piston has past the dead centre at the end of the exhaust stroke.

The air-valve cam, like that of the exhaust-valve, begins the opening an instant before the end of the exhaust stroke and holds the valve open until after the dead centre of the suction stroke is past.

The starting-valve opens just before the beginning of the working stroke, but closes some little time before the end of the stroke. The starting-valve has a wider opening and a longer open period than the fuel-valve, but does not remain open as long as the exhaust-valve or the air-valve.

THE TWO-CYCLE DIESEL ENGINE. Diesel engines are built on the two-cycle as well as on the four-cycle principle.

The two-cycle Diesel engine, like the two-cycle gasoline-engine, is not quite so efficient as the four cycle, because of the fact that it is more difficult to get a perfectly pure charge entirely unmixed with any burned gases; but it has the advantage of two working strokes to one of the four-cycle engine, and the construction is less complicated. Inasmuch as a supply of compressed air is necessary for working a Diesel engine, a part of this can be easily diverted for scavenging the engine at the end of the exhaust stroke, and, thus, a good preparation can be made for the suction stroke.

More often, however, a separate air-cylinder is used for pumping air and discharging it through the main cylinder, without compression. Fig. 162 shows a section of a simple form of the two-cycle Diesel engine.

On the left of the cylinder is shown the exhaust-port which is uncovered by the piston as it nears the end of its stroke. On the right, is shown an air passage, for scavenging purposes, which is uncovered by the piston a little later than is the exhaust passage. The piston is of such shape that the entering air is diverted toward the top of the cylinder and then follows up the exhaust in such a way that the burned gases are very effectually cleared out of the cylinder before the return stroke begins. Sometimes the latter part of the air-blast is used for the air charge and at other times a separate screened charge is let in at the top, as in the

case of the four-cycle engine. In either case there is no waste of fuel, as in the case of the two-cycle gasoline-engine, on account of a part of the charge blowing

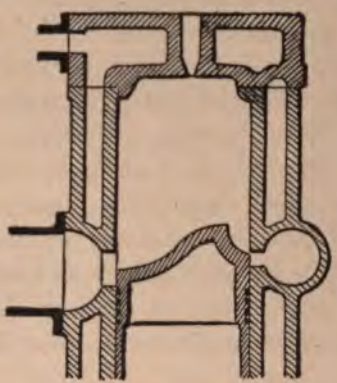

FIG. 162

through the exhaust before the exhaust-port is closed by the returning piston, for the fuel is introduced only at the end of the compression stroke, in the same manner as has been described for the four-cycle Diesel engine.

Not only does the exhaust-port open sooner than the scavenger port, but it closes later, and thus full opportunity is given for the burned gases to escape before compression begins.

In Fig. 162 all valves and other accessories are left out for the sake of clearness in explaining the points under consideration.

Multiple-Cylinder Diesel Engines

Inasmuch as there are many pieces connected with the valves and valve mechanisms of Diesel engines which can best be manufactured in uniform sizes, it is a common practice, among manufacturers, to increase the capacity by multiplying cylinders rather than by making many different sizes of single-cylinder engines. In marine work, especially, it is common to use four, six, and eight cylinders on a single shaft. These are often two-cycle cylinders; and it is common to have one or more extra cylinders pumping air, for scavenging purposes, attached to the same crank-shaft. Of course the use of multiple cylinders involves much care in manufacturing and fine adjustment of the many parts, so as to have everything work harmoniously.

The Diesel engine uses fuel economically, when properly built and adjusted; but a little careless workmanship or lack of proper maintenance will often offset all the advantages of its use over that of internal-combustion engines of less complicated nature.

The first cost of a Diesel engine is more than that of other forms of internal-combustion engines, and it only has the preference where economy of fuel and operation are very important considerations.

Diesel engines are always heavy because of the great strain entailed by high compression and the usual great length of cylinder and piston.

Oiling arrangements are usually automatic and quite complicated, with pipes leading to all important jour-

nals. Because of the very high air pressure required to inject fuel oil into already highly compressed-air charges, the tanks for this supply are usually small in diameter and made up of several units.

The Semi-Diesel Engine

We have seen that the characteristics of the Diesel engine are: high compression, the introduction of the fuel at the instant of ignition, and the use of fuels not otherwise available. We have also seen that an engine working on the Diesel principle is a very complicated and costly piece of mechanism—economical in operation, but costly to build. The success of the Diesel engine has led to the adoption of some of its principles in less costly though fairly efficient internal-combustion engines for marine and stationary work. Fig. 163 shows a sectional view of a two-cycle semi-Diesel internal-combustion engine having practically no valve mechanism and of very simple construction. It is very much like the two-cycle gasoline-engine previously described, but it differs from it in the following particulars: The fuel is introduced at the end of the compression stroke, it burns oil, and the charge is ignited in a different way.

This form of engine is sometimes called the "hot-pot" engine, and it is much used on fishing-boats of the North Sea.

In the cylinder-head there is a cavity, *A*, which forms a part of a combustion-chamber which, by the way, is much larger than that of the Diesel engine proper.

This cavity is connected with the cylinder by means of passages, as shown. Ignition is effected by first heating the walls of the cavity red-hot by means of a blow-lamp—through the opening in the top covering, shown at the left. After the engine is under way, the

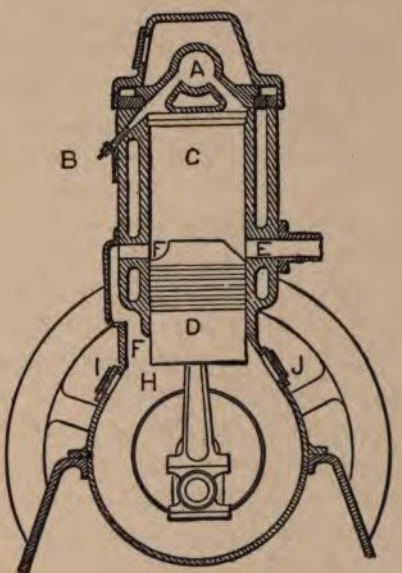

FIG. 163

repeated ignition of the charge keeps up sufficient heat in the metal to insure ignition whenever fuel oil is injected into the cavity. *B* shows an oil injector which must, of course, be connected with an oil-supply by suitable piping. The piston, *D*, is shown at the bottom of its travel.

The cylinder, *C*, is of sufficient length to allow a good-sized combustion-chamber when the piston is at the upper limit of its travel. *E* is the exhaust passage, and *F*, *F* is a by-pass connecting the cylinder with the enclosed crank case. *I* and *J* are air inlet valves. When the piston rises it draws pure air, through the valves *I* and *J*, which is compressed in the crank case as the piston descends.

When the piston has nearly reached the lower limit of its travel, it uncovers the upper end of the by-pass, *F*, and the compressed air in the base rushes through into the cylinder.

As the piston rises on the next stroke it compresses this air in the cylinder and combustion-chamber, and, at the right moment, near the end of the up stroke, fuel oil is injected into the "hot-pot," *A*. Combustion then takes place; the expanding gas drives the piston down, and the cycle is completed.

The piston uncovers the exhaust-port, *E*, a moment before it uncovers the inlet, so the burned gases are on their way out before the fresh air enters.

A deflector sends the fresh-air charge to the top and helps to clear the cylinder of all burned gases. On the up stroke, too, the exhaust-port remains open until after the inlet is closed, so there is no danger of any burned gases being driven back into the crank case.

Compression at the time of the injection of the fuel amounts to only about one hundred and fifty pounds to the square inch, so the heat produced by compression alone is not sufficient to ignite the charge—as in the case of the Diesel engine proper. Repeated ignition

in the "hot-pot," as already stated, keeps up a sufficiently high temperature in the metal to start combustion of the fuel oil whenever it is injected for the power stroke.

Either a supply of compressed air or a direct-acting pump is necessary for the purpose of injecting the fuel oil into the hot-pot, but it is not necessary to maintain the very high tension required in the case of the Diesel engine proper.

Other details are not essentially different from those of the two-cycle Diesel engine.

INDEX

A

Action of steam-jet, **132, 133, 134,** 135
Air, 24
Air cooling, 236
Airplane engine, 238
Air-pump, 25, 98
Anthracite coal gas producer, 185
Aquitania, the, 48
Atmosphere, 24
Atmospheric engine, 21
Atmospheric pressure, 24
Auxiliary air compressor, 256
Auxiliary valve, 71

B

Balance, of cranks, 74; of impulse rotors, 138
Balanced valves, 70
Bearings, 79; thrust, 80
Bed, engine, 79
Bell-crank, 91
Bituminous coal gas producers, 190
Blades of turbine-engines, 135; fixed, 150; movable, 150, 151
Boiler, 39; accessories of, 42; batteries of, 45; calking of, 53; double enders, 48; heating surface of, 41; joints of, 52; marine, 46; single enders, 46, 47; tubular, 44; vertical, 40; water-tube, 52
Boulton, M., Watt's partner, 34
Brake, 175
Brake horse-power, 174
Branca, engine of, 129
By-pass, 227
By-products of gas producers, 190

C

Calking, 52
Cam, 191
Capacity of small shafts, 139
Carbon dioxide, 186; monoxide, 185
Carburetor, 206
Centre of gravity, 138
Centrifugal force, 136; governor, 85; pump, 235
Chain-block, 16
Chain-grate, 55
Chimney, 38
Coal, anthracite, 187; bituminous, 190; economy in the use of, 56
Coal-gas, 185
Cog-wheels, 8
Coke, 188
Combustion-chamber, 45, 180
Compound engine, 96
Compressed air, 252
Condensers, 28; jet, 98; surface, 99
Condensing engines, 21, 26
Conductors, 216
Conical tread, 111
Connecting-rods, 63, 76
Corliss, George H., 87; engine of, 87; valves, 87; valve-gears, 89
Cranks, 31, 74; balanced, 74; double, 75; 120 degree, 232
Cross-heads, 72, 73
Cugnot's steam-carriage, 102
Cut-off, 31, 67
Cylinders, 18; double-acting, 18; gas-engine, 178; multiple-steam, 96; single-acting, 18; tandem, 95

D

"D"-valve, 62, 65
Dash-pot, 93
Dead centres, 66
De Laval, Dr., 134; engine of, 134; rotors, 136, 137; steam-nozzle, 135
Diagrams, 170, 173, 174, 213, 253
Diesel, Dr., 250; claims of, 251
Diesel engines, 250; advantages of, 252; details of, 256; economy of operation, 251; high

cost of manufacture, 267; low cost of fuel, 250; method of starting, 261; multiple-cylinder, 267; peculiar cylinder-head, 256; scavenging, 265; two-cycle, 265
Double-acting engines, 32
Double-ended boiler, 48
Double-impulse rotors, 140, 144, 145, 158
Draft, 38
Drawbar pull, 164
Driving-blocks, 109
Driving-wheels, 111
Dry cell, 216
Dry steam, 46
Dummies, 153

E

Early engines, 21
Eccentric, 64; strap, 64; rod, 64
Efficiency, 165
Electricity, 215
Electric-light engines, 177
Electric spark, 212
Energy, 164; active, 165; potential, 165
Engines, 21; airplane, 238; atmospheric, 21; compound, 95; condensing, 26, 28; Diesel, 250; double-acting, 32; four-cycle, 180; gas, 178; gasoline, 197; horizontal, 62; internal-combustion, 178; marine, 99; oil, 249; quadruple expansion, 97; reciprocating, 62; triple expansion, 97; two-cycle, 226; "V"-type, 233; vertical, 84
Equalizing bars and hangers, 110
Exhaust-ports, 62, 65, 87
Expansion of steam, 30
Expansive working, 30
Extra air-valve, 208

F

Feed water, 100
Fire-box, 40, 46
Fires, 37; closed, 38; open, 38; semi-open, 37
Flanges, 111
Flexible bearing, 146
Flexible shaft, 138
Fly-wheel, 31
Foot-pounds, 164
Force, 164
Forced draft, 50
Formula, 167
Four-cycle engine, 180
Frames of locomotives, 108
Friction, 12
Fuel, 37; coal, 37; gas, 178; gasoline, 197; oil, 249
Fulcrum, 3
Furnaces, 39

G

Gas, 178; dioxide, 186; monoxide, 185; producer, 186
Gas-engines, 178; governor of, 191; ignition of, 181, 182; pistons of, 180, 182; pressure in cylinders of, 183; principle of, 180; starting, 180; water-jacket of, 180
Gas producer, 185
Gasoline-engine, 197; cam-shaft, 202; carburetor, 206; crank-case, 202; cylinder, 202; electric sparking device, 225; four-cycle, 201; lubrication of, 203, 267; piston, 18, 245; radiator, 235; spark-plug, 220; "T"-type, 201; two-cycle, 226; "V" type, 233; valve-in-head type, 204; valves, 202; water-jackets, 235
Gauge, 84
Geared turbine, 142
Gearing, 8
Gland, 84
Governors, 85, 191
Grates, 37, 40, 44, 55
Gravity, 164
Guides, 63, 120
Gusset-stay, 51

H

Heat, the result of chemical action, 37; conversion of into mechanical energy, 27

Hero's engine, 128
High-pressure boilers, 36
High velocity of rotors, 138
"Hit and miss" governors, 193
Horizontal engine, 61
Horse-power, brake, 174; indicated, 174; meaning of, 165; measuring of, 168
Hot-pot, 268

I

Ignition, hot-pot, 268; hot-tube, 181; jump-spark, 220; make-and-break, 219
Impulse turbine, 135
Inclined plane, 10
Indicated horse-power, 174
Indicator, steam-engine, 168
Induced current, 221
Induction coil, 221
Injector, 122
Insulation, 219
Internal-combustion engines, 178

J

Jet condensers, 98
Joints, steam-tight, 57
Jump spark, 220

K

Kilowatts, 165
Kingan-Ripkin valve-gear, 116

L

Lap, 65
Lead, 66
Lean mixture, 210
Lever, applications of, 4, 5, 6, 7, 8, 9; discovery of its use, 2
Liberty motor, 238; comparison with earlier types, 248; its extreme lightness, 240
Link motion, 80
Locomotive, details of, 107–127, inclusive; driving-wheels, 111; early types, 102; for freight service, 9; for passenger service, 9, 106; modern types, 105, 106
Longitudinal stays, 51
Low pressure, 36
Lubrication, 203, 267

M

Machine, 1
Manholes, 43
Manifolds, 211, 247
Make-and-break system, 219
Marine boilers, 46
Marine engines, 99
Metallic packing, 83
Meyer's expansion-valve, 71
Mixture of gas and air, 206
Momentum, 132
Multiple-cylinder engines, 96, 230
Mushroom-valves, 256

N

Newcomen, Thomas, 21; boiler of, 36; engine of, 22
Nozzles, turbine, 130, 131, 132, 135

O

Oil, engines, 249; fuel, 250; lubricating, 185
Overheating, 184

P

Packing, cotton-waste, 84; metallic rings, 83
Parsons, Charles A., 148
Parsons steam-turbine, 151
Petroleum, 185
Pillow-block, 79
Pistons, 18, 83
Piston-valve (*see* cylindrical slide-valve)
Poles, 220
Pony truck, 105
Pop-safety valve, 124
Ports, 62
Potential energy, 165
Power, definition of, 165; measurement of, 166
Pre-ignition, 215
Pressure, 170; atmospheric, 24; boiler, 36; high, 96; intermediate, 97; low, 97; measurements of, 120; steam, 36
Pressure diagrams, 170, 173, 174, 175
Primary winding, 224

Priming, 205
Producer, gas, 186; suction, 190
Pulley, 16
Pump, 235
Pumping-engine, 21

Q

Quadruple expansion-engine, 97

R

Radiators, 235
Reaction, 149; turbine, 150
Reaction blading, 149, 150; method of mounting, 156
Reciprocating engines, 61
Reduction of fuel consumption, 248
Return-crank, 117
Reversing chamber, 145
Reversing-gear, 80, 116
Reversing-lever, 58
Rings, packing, 83
"Rocket," the, 103
Rod, connecting, 61, 76; eccentric, 64; piston, 33, 61; valve, 64
Rotors, combination, 153; De Laval, 137; Parsons, 151

S

Safety device, 147
Safety-valve, spring, 124; weighted, 42
Secondary winding, 221, 222, 223
Semi-Diesel engine, the, 268
Separator, steam, 101
Series, 218
Series parallel, 218
Shaft, 61
Single-cylinder engine, 62
Single-ended boiler, 48
Slide-valve, plain "D," 65; cylindrical, 113
Smoke-box, 104
Spark, 212
Spark-plug, 220
Speed of rotors, 136; of steam-jet, 131; critical, 138
Springs, 104, 109
Standard gauge, 105
Starting devices, 208; Diesel engine, 258
Stays, gusset, 51; longitudinal, 51
Steam-dome, 46
Steam-engine, admission of steam to, 62; compound, 95; condensation of steam in, 21, 27; Corliss, 87; double-acting, 31; marine, 84, 99; ports of, 62, 87; quadruple-expansion, 97; reciprocating, 61; single-acting, 31; triple-expansion, 97; vertical, 84
Steam-gauge, 120
Steam-nozzle, 135, 145
Steam pressure, 36; jet, 132; nozzles, 135, 145
Steam separator, 101
Steam-turbines, 128
Steam-whistle, 125
Stephenson, George, 102
Stresses, 215
Stroke, 203
Stuffing-box, 84
"Sun-and-planet" motion, 31
Superheated steam, 55
Superheater, 55
Surface condenser, 99

T

Tackle and fall, 16
Tandem engines, 95
Tar fuel, 251
Thermodynamics, 162
Three-point suspension, 111
Throttle control, 115
Throttle governing, 86
Throttle-valve, 115
Thrust-block, 80
Timer, 226
Timing-gears, 203
Tires of locomotives, 111
Tractive force, 106
Trevithick, Richard, 102
Triple expansion-engine, 97
Trunk-piston, 18
Tubular boiler, 44
Turbines, ahead, 161; astern, 161; diagrams of, 152, 154, 155; disadvantages of, 161; exhausts

of, 140; impulse, 134; reaction, 148; Westinghouse, 152
Turbo-generators, 143
Two-cycle engine, 226
Two-cylinder engine, 230

V

"V"-type of gasoline-engine, 233
Vacuum, 26
Vacuum-tank, 212
Valve-gears, Kingan-Ripkin, 116; Stephenson, 80, 81, 82; Walschaert, 116
Valves, auxiliary, 71; balanced, 70; check, 19; Corliss, 87; cylindrical slide, 114; "D"-slide, 65; mushroom, 256; piston (*see* cylindrical slide); throttle, 115; safety, 42, 124
Velocity, 161; of steam-jet, 131
Velocity diagrams, 140
Vertical boiler, 40; engine, 84
Vibrator, 223

W

Walschaert, 116
Waste, of fuel, 56; of heat, 39
Water-gas, 187
Water-jacket, 180
Watt, James, 26; air-pump of, 28; business success of, 30; condenser of, 28; contribution toward modern progress of, 35; double-acting cylinder of, 32; engine of, 28; experiments of, 27; parallel motion of, 33; single-acting cylinder of, 28; sun-and-planet motion of, 32
Weight of steam, 162
Westinghouse company, 143
Wheels of locomotives, 9
Work, 164
Working power, 175
Wright Brothers, the, 248; weight of their engines per horse-power, 248